Competition: Controlled Replication for Higher Reliability and Predictability in Industrial IoT Networks

Hao Jiang
Télécom Bretagne, France

Zacharie Brodard
Ecole Polytechnique, France

Tengfei Chang
EVA team, Inria, France

Ahmed Bouabdallah
Télécom Bretagne, France

Nicolas Montavont
Télécom Bretagne, France

Geraldine Texier
Télécom Bretagne, France

Pascal Thubert
Cisco Systems, France

Thomas Watteyne
EVA team, Inria, France

Georgios Z. Papadopoulos
Télécom Bretagne, France

Abstract

Applications such as the smart grid or vehicle automation require deterministic transmissions with properties such as on-time data deliveries and end-to-end reliability close to 100%. We introduce a novel mechanism based on BIER-TE, a scheme in which parallel transmissions over several paths are scheduled, while promiscuous listening between the paths enables nodes to possibly overhear transmissions on the other. We propose an implementation of this new approach for the dependability competition.

Keywords

Multi-path Routing Algorithm, Path Diversity, BIER-TE

1 Introduction

In the context of the dependability competition, we propose a novel routing protocol which aims at providing deterministic networking over a lossy wireless medium. This work is issued from the needs for the Industry 4.0, an emerging concept which consists in reusing the Internet of Things (IoT) technologies to simplify the production chains, ease the deployment and make the factory more flexible. In this context, communications need to be deterministic.

Determinism in a network brings the guarantee that a particular information is transported across the network in a tight window of time, and that a periodic process will be repeated identically every time [3]. To this aim, a deterministic flow must traverse the network in the same predictable fashion every time, regardless of the load of the network, the link quality, and the network congestion. However, the deployed IoT technologies are based on best-effort packet switched network, where the data packets are subject to variable delay in the network, due to retransmissions and enqueuing in intermediate nodes.

International Conference on Embedded Wireless
Systems and Networks (EWSN) 2017
20–22 February, Uppsala, Sweden

ISBN: 978-0-9949886-1-4

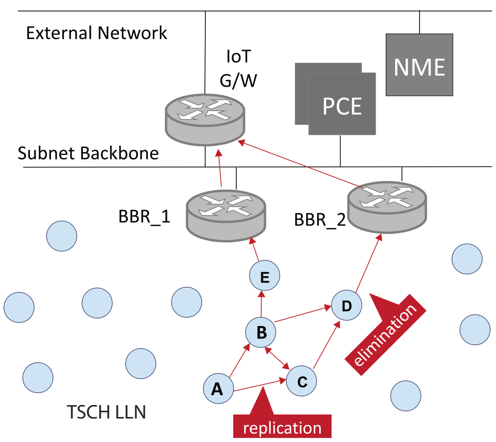


Figure 1: Packet replication and elimination.

In 2016, the IEEE 802.15.4-2015 standard [1] was published to offer Quality of Service (QoS) for deterministic industrial applications. Time-Slotted Channel Hopping (TSCH) is among the Medium Access Control (MAC) protocols defined in this standard, which combines Time Division Multiplexing (TDM) with channel agility in order to defeat interference. However, it does not avoid retransmissions, since links are subject to losses, so wireless transmissions are typically associated with a retry mechanism, such as Automatic Repeat-reQuest (ARQ). Retransmission comes at a cost in terms of delay (in best-effort traffic), energy consumption and bandwidth, since it requires additional time slots. Typically, if a transmission of a data packet fails, the sending node may need to wait for the next slotframe to retry. If the transmission of a data packet failed after several retries, the routing protocol (RPL in our case) uses fail-over mechanism, but the delay in discovering and using an alternative path is often very long.

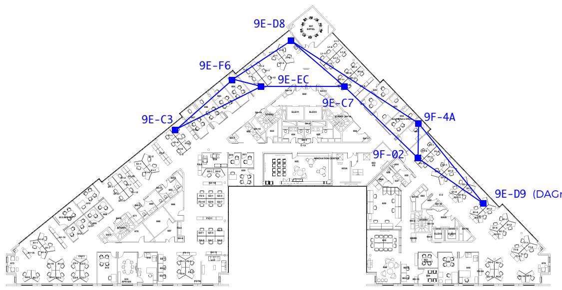


Figure 2: Bird view of the testbed deployed at Cisco PIRL.

We propose to enhance the forwarding mechanism in RPL-based network to duplicate the data flow on an alternate path. This allows anticipating potential link errors on a single path and exploiting path diversity in a dense network. We show that determinism can be guaranteed by using multiple parallel data paths, and thus provide high delivery rate and a very low jitter.

2 BIER-TE: Toward Multipath Redundancy

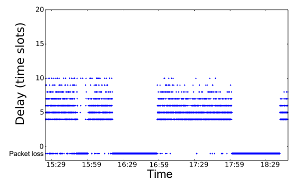
We propose to extend Bit Index Explicit Replication with Traffic Engineering (BIER-TE) mechanism defined at the IETF [2]. The BIER header contains a bitmap in which each bit represents exactly one egress router in the domain. To send a packet to a particular set of egress nodes, the ingress node sets the bits for each of those egress nodes, and clears other bits in the bitmap.

BIER-TE uses explicit hop-by-hop forwarding and loose hop forwarding of packets. The source of a data packet (which can also be the ingress router) inserts a bitmap in the packet header to inform nodes whether to forward, eliminate or replicate packets. Each bit of the bitmap represents an adjacency between two nodes. BIER-TE thus relies on a BIER-TE controller which learns the network topology, computes paths, and assigns a bit index to each adjacency. Moreover, it installs in each of the nodes a Bit Index Forwarding Table (BIFT), indicating how to forward a packet according to the packets bitmap. On the destination node, the bitmap present in the packet when it reaches the destination is inspected by the controller which identifies transmission failures and learns the link conditions. The controller accordingly modifies the bitmap for next packets, thereby dynamically controlling the replication and elimination activities according to the QoS requirements. In the implementation that we will propose for this competition, we will determine how packets can be duplicated in the network in order to reach 100% delivery ratio, and a jitter close to 0 by minimizing (or even avoiding) retransmissions.

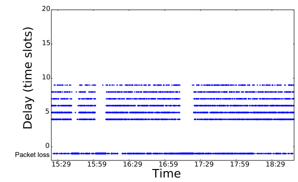
3 Performance Evaluation

A set of experiments were conducted to evaluate BIER-TE using the testbed shown in Fig. 2, with an IEEE802.15.4-2015 TSCH LLN composed of 8 OpenMotes running OpenWSN[1] firmware in the data plane and a controller in the control plane. The motes are distributed on the sixth floor

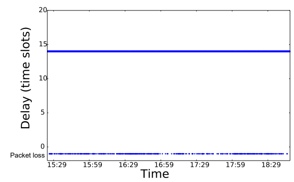
[1] www.openwsn.com



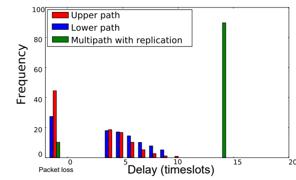
(a) receiving delays for packets along upper path over time.



(b) receiving delays for packets along lower path over time.



(c) receiving delays for BIER-TE packets with multipath over time.



(d) frequency (% of packets sent) of receiving delays (in timeslots).

Figure 3: Performance of BIER-TE, when compared with retry-based single path. Delay of -1 means a packet loss.

at Cisco PIRL with a topology in a general shape of a ladder. In order to compare the results to the situation without BIER-TE, the source node `9E-D9` is configured to transmit 3 packets every 2.5 s. Two single-path packets take the lower and upper path, respectively, with limited retries at each hop. One multi-path packet takes a complex path with packet replication and elimination enabled by BIER-TE.

Fig. 3 shows the results of the experiment:

Retransmissions have a straightforward impact on jitter. The more retransmissions at the MAC layer, the higher the jitter. On the contrary, BIER-TE presents zero jitter and stable performance throughout the experimental lifetime.

Packet replication along alternative paths effectively overcomes link or node failure, which increases reliability and reduces burst packet losses. Retransmissions are less immune to burst losses, and if a transmission failed, using retries has greater chance to fail again.

4 Conclusion

Issued from the Industry 4.0 needs, the IoT technology is moving toward deterministic wireless networks. We propose a new mechanism with replication to transport data packets in a predefined and constant delay. We expect attendees to experience the functionality and consequently the gain of BIER-TE under harsh environmental conditions.

5 References

[1] IEEE Standard for Low-Rate Wireless Personal Area Networks (LR-WPANs). *IEEE Std 802.15.4-2015 (Revision of IEEE Std 802.15.4-2011)*, April 2016.

[2] T. Eckert, G. Cauchie, W. Braun, and M. Menth. Traffic engineering for bit index explicit replication. Internet-Draft draft-eckert-bier-te-arch-04, IETF Secretariat, September 2016. https://tools.ietf.org/id/draft-eckert-bier-te-arch-04.txt.

[3] T. Matsui, G. Z. Papadopoulos, P. Thubert, T. Watteyne, and N. Montavont. Poster: 4th Industrial Revolution: Toward Deterministic Wireless Industrial Networks. In *Proceedings of the International Conference on Embedded Wireless Systems and Networks (EWSN)*, 2017.