First Study of the Proactive Transmission of Replicated Frames Mechanism over TSN

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EUROPEAN UNION — EUROPEAN REGIONAL DEVELOPMENT FUND — "A way to make Europe"

This work is supported in part by the Spanish Agencia Estatal de Investigacin (AEI) and in part by FEDER funding through grant TEC2015-70313-R (AEI/FEDER, UE). Ines Alvarez and Drago Čavka was supported by a scholarship of the EUROWEB+ Project, which is funded by the Erasmus Mundus Action II programme of the European Commission.

EUROWEB — European Research and Education Collaboration with Western Balkan
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Abstract

Time-Sensitive Networking (TSN) is a task group from the IEEE working to provide Ethernet with **flexibility, real-time** and **reliability services.**
For these reasons, **TSN** represents an appealing technology for the networks of **Cyberphysical Systems**.
Nevertheless, TSN **does not cover some reliability aspects** that are important to reach the reliability levels required by certain Cyberphysical Systems.
Specifically, TSN does **not devise any time redundancy mechanisms in the layer 2 to tolerate temporary faults** in the channel.
Thus, we proposed a time redundancy mechanism, called **Proactive Transmission of Replicated Frames**, to increase the reliability of TSN-based networks.
In this work we describe two previous designs of PTRF and we present a new design. We also describe the simulation model used to compare the designs. Specially, we carried out exhaustive fault injection to validate the mechanism and a case study to compare the three designs.

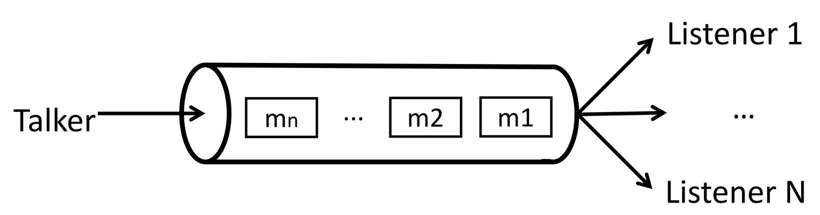
Time-Sensitive Networking Overview

TSN is a set of standards that aims at providing **Ethernet** with **hard real-time**, on-line **management** and **reliability** services.

To provide timing guarantees and enable on-line management of the network TSN relies, among others, on the SRP.

SRP enables the **reservation of resources along the path between two nodes** that want to communicate to guarantee availability and bounded transmission times.

The **communication is done through** virtual communication channels called **streams** and the resource reservation is done in a per-stream manner.

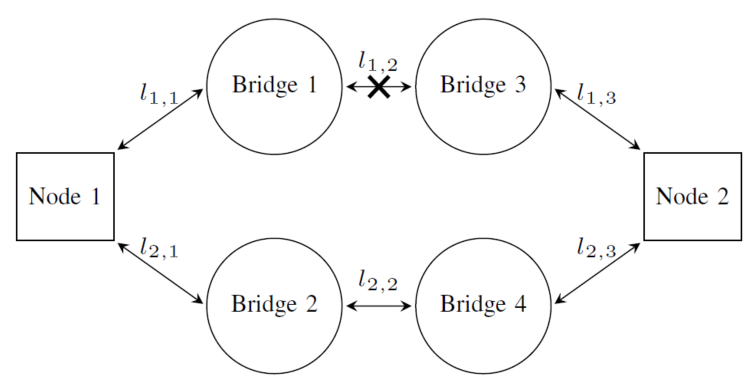


Problem

TSN **does not provide** any time-redundancy mechanisms in this level of the architecture specifically designed to **tolerate transient faults**. Although TSN can use **higher level protocols**, such as those based in **Automatic Repeat Request** (ARQ), this solution is not good enough in real-time systems.

Using spatial redundancy to tolerate temporary faults is not adequate:

- The communication channel is specially vulnerable to transient faults.
- Spatial redundancy has high impact in the cost and size of the system.
- When permanent faults cause the attrition of the spatial redundancy, it may not be possible to tolerate transient faults any more.

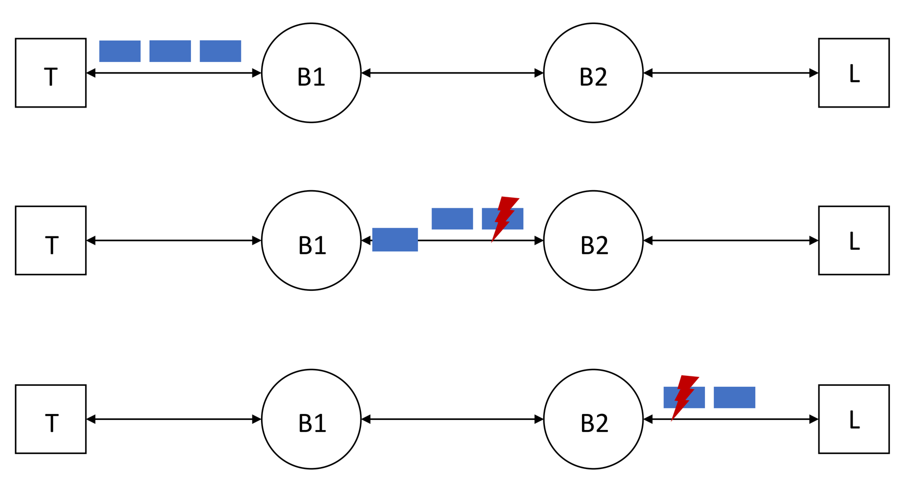


In this work we evaluate time redundancy through exhaustive fault injection and an automotive use case

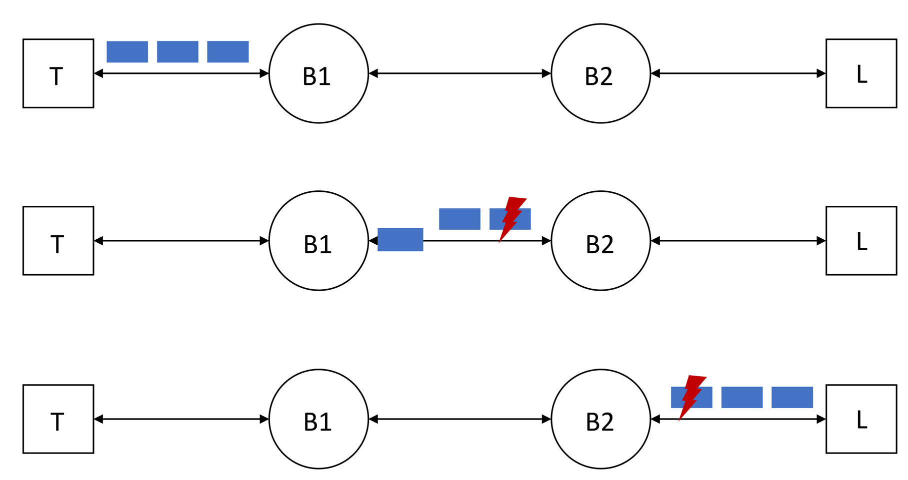
Proactive Time Redundancy

Use Proactive Transmission of Replicated Frames (PTRF) to tolerate temporary faults and TSN spatial redundancy to tolerate permanent faults in the links.

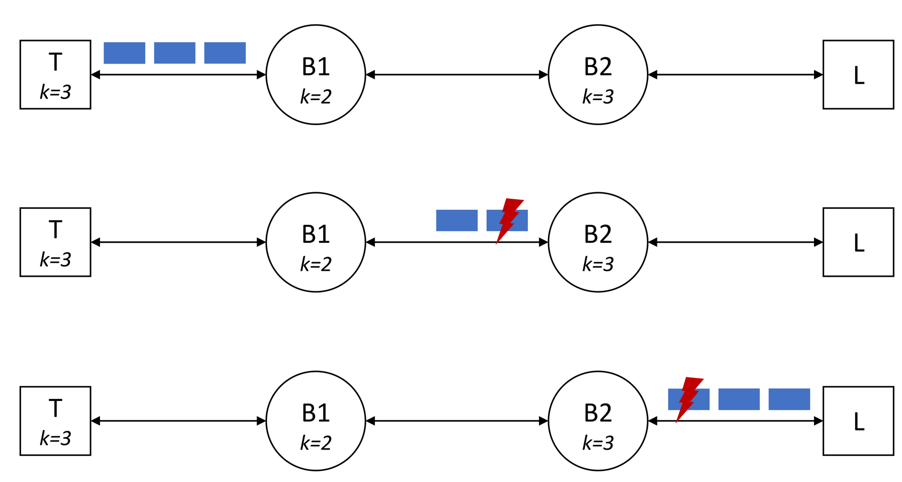
E2E estimation and replication of frames (A)



E2E estimation, link-based replication of frames (B)



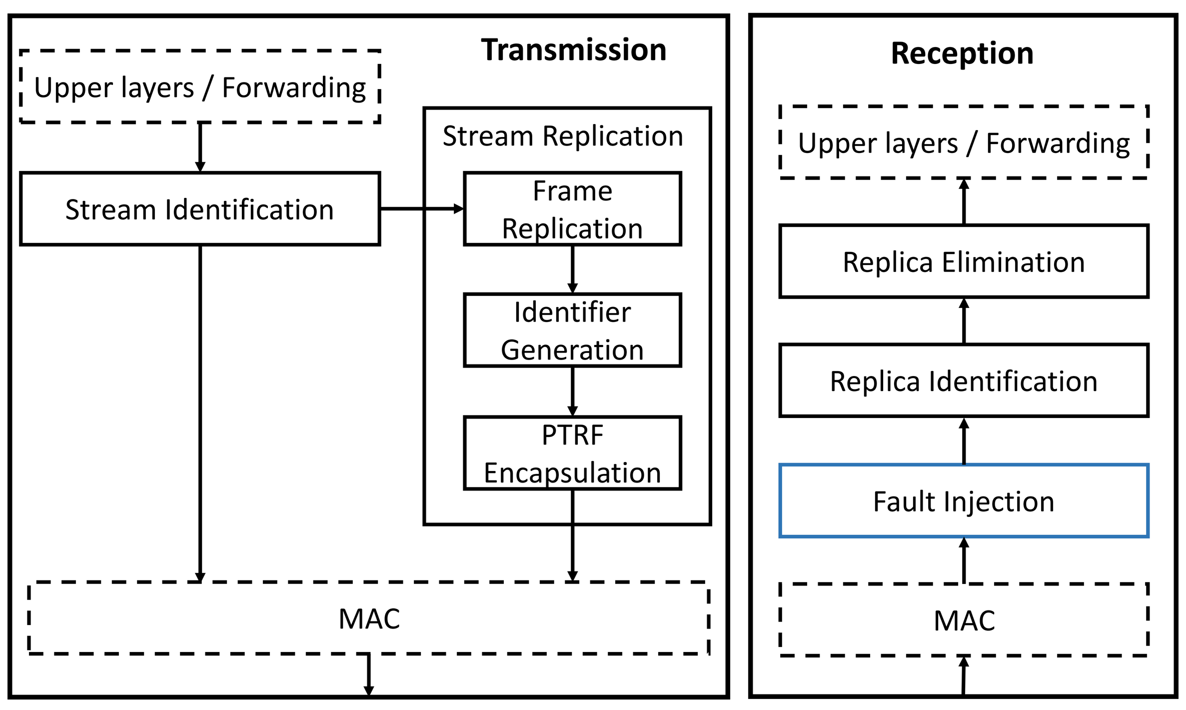
Link-based estimation and replication of frames (C)



OMNeT++ simulation model

We used simulation to evaluate and compare the proposed approaches.

Modules on transmission and reception



Frame Structure

Field	bytes
Destination MAC address	6
Source MAC address	6
C-tag EtherType	2
Priority, DE, VLAN ID	2
TRM EtherType	2
Message Identifier	2
Number of Replicas (k)	1
Payload Length/EtherType	2
data	n
Frame Check Sequence	4

Exhaustive fault injection

Inject all the possible combinations of errors where at least one replica traverses each link.

(A)

$$\sum_{e_1=0}^{k-1} \cdots \sum_{e_l=0}^{k-e_1-\cdots e_{l-1}-1} \left(\prod_{m=1}^{l} \binom{k-\sum_{i=1}^{m-1} e_i}{e_m} \right)$$

(B)

$$\left(\sum_{e'=0}^{k'-1} \binom{k'}{e'} \right)^{l}$$

(C)

$$\prod_{m=1}^{l} \sum_{e''=0}^{k''_m-1} \binom{k''_m}{e''}$$

$\boldsymbol{k, k', k''_m}$: number of replicas in the link
$\boldsymbol{e, e', e''_m}$: number of errors in the link
$\boldsymbol{l}$: number of links in the path

The goal of these experiments is twofold:

- Verify the correct operation of the mechanism.
- Compare the approaches in terms of number of scenarios that can be tolerated.

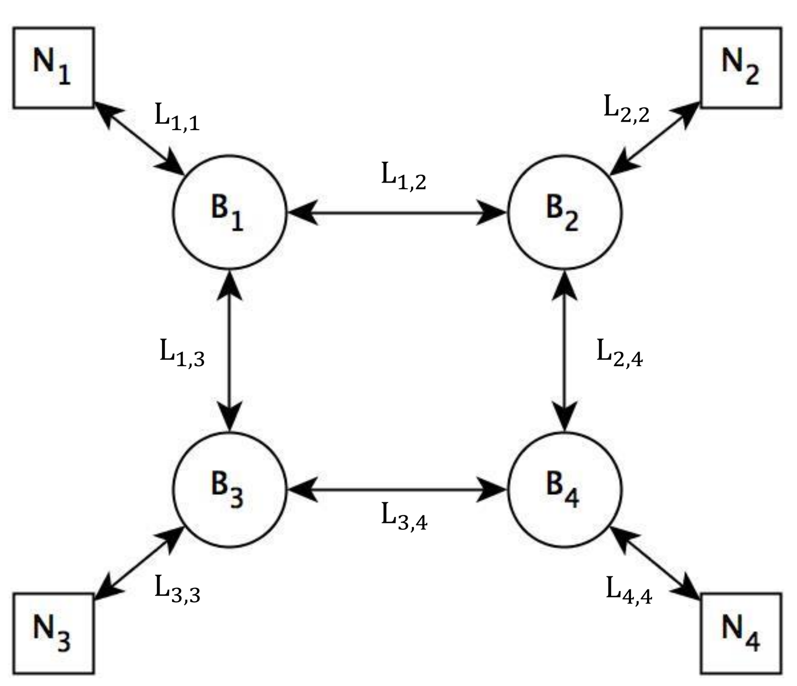
The network parameters used are:

- 6 hops (6 bridges between talker and listener).
- 100 Mbps.
- No interfering traffic.

Approach	Replicas	Combinations	Max. Delay (µs)
A	3	169	92.08
B	3	823543	212.18
C	2342342	297675	202.13

Automotive use case

Topology



Experiments parameters

Traffic parameters, with 100Mbps and all nodes receive all streams.

Type	Priority	Size (B)	Period (ms)	Sender
Control	7	72	10	N_1
ADAS	5	1526	30	N_2
Video	3	1400	0.28	N_3
Audio	2	1400	1.4	N_4

Number of replicas transmitted depending on the BER .

BER	# Selected replicas			
	Control	ADAS	Video	Audio
10^{-12}	2	2	1	1
10^{-11}	3	2	1	1
10^{-10}	4	3	1	1

Network configuration for each experiment. The variance on the BER represents the changing environmental conditions.

Experiment	$L_{1,1}$	$L_{2,2}$	$L_{3,3}$	$L_{4,4}$	$L_{1,2}$	$L_{1,3}$	$L_{2,4}$	$L_{3,4}$
1	10^{-12}	10^{-11}	10^{-12}	10^{-11}	10^{-12}	10^{-12}	10^{-11}	10^{-11}
2	10^{-12}	10^{-10}	10^{-11}	10^{-10}	10^{-12}	10^{-12}	10^{-10}	10^{-11}
3	10^{-11}	10^{-10}	10^{-11}	10^{-10}	10^{-11}	10^{-11}	10^{-10}	10^{-10}

Results

Lost frames in the longest link and lost in total in all the links.

Approach	Traffic type	Exp. 1	Exp. 2	Exp. 3
A	Control	0	4	2
	ADAS	0	8	2
	Video	14	148	176
	Audio	6	25	56
	Total	53	400	619
B	Control	0	2	2
	ADAS	1	8	0
	Video	17	163	173
	Audio	7	38	60
	Total	58	436	624
C	Control	0	2	3
	ADAS	1	3	5
	Video	11	142	172
	Audio	8	37	73
	Total	55	412	626

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