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

Inés Álvarez, Drago Čavka, Julián Proenza, Manuel Barranco



Introduction

- Time-Sensitive Networking (TSN) Task Group.
- Developing a set of standards to provide Ethernet:
 - REAL-TIME GUARANTEES,
 - ONLINE MANAGEMENT,
 - RELIABILITY
- on the layer 2.

Introduction

- Time-Sensitive Networking (TSN) Task Group.
- Developing a set of standards to provide Ethernet:
 - REAL-TIME GUARANTEES,
 - ONLINE MANAGEMENT,
 - **RELIABILITY**
- on the layer 2.

Reliability in TSN

- Qci: Per-Stream Filtering and Policing.
- Error containment.
 - Detect babbling idiot.
 - Detect delayed frames.

Reliability in TSN

- Qca: Path Control and Reservation
 - Establish multiple paths between nodes.
- CB: Frame Replication and Elimination for Reliability
 - Establish logical links over the created paths.
 - Send replicated messages through the redundant links.

Reliability in TSN

- TSN does not have time redundancy on layer 2.
- What are the options to tolerate temporary faults?

Reliability in TSN

- Using spatial redundancy to tolerate temporary faults.
- Not a suitable solution:
 - High cost.
 - No efficient solutions (specially in highly critical systems).

Reliability in TSN

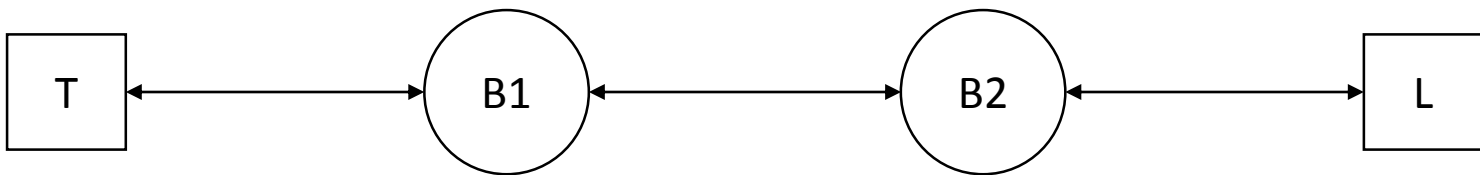
- Using ARQ-based protocols.
- Not a suitable solution (for HRT systems):
 - High jitter.
 - Non-deterministic bandwidth consumption.
 - ACK/NACK messages introduce new fault scenarios.

Reliability in TSN

- We propose to use proactive retransmissions.
- Lower cost than adding more paths.
- Lower jitter than with ARQ.
- Deterministic bandwidth consumption.
- More efficient than ARQ in the worst case scenario.

Proactive Transmission of Replicated Frames

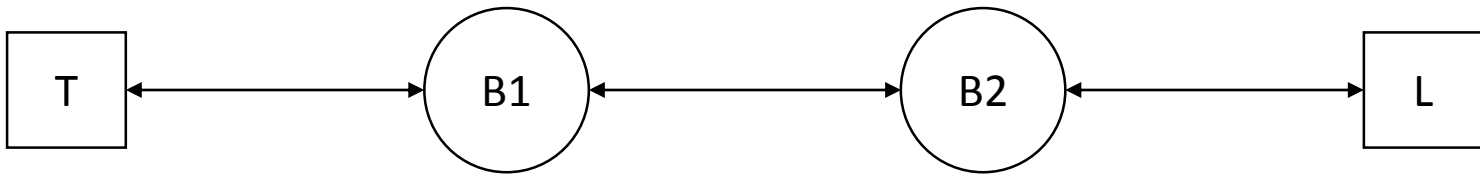
End-to-end estimation and replication



Proactive Transmission of Replicated Frames

End-to-end estimation and replication

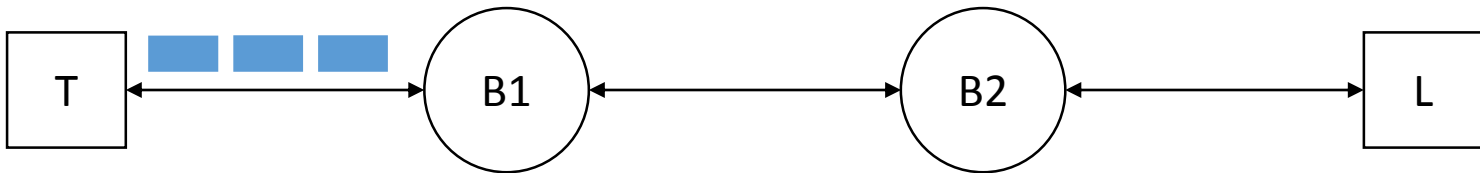
$k=3$



Proactive Transmission of Replicated Frames

End-to-end estimation and replication

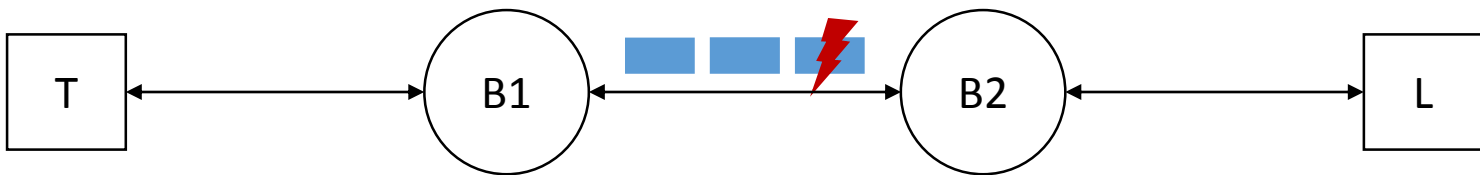
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Proactive Transmission of Replicated Frames

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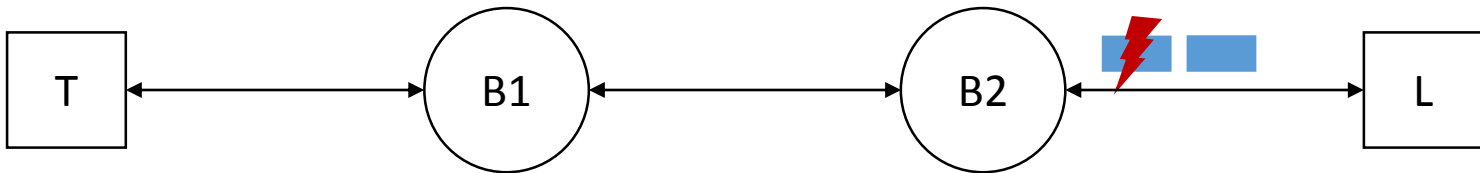
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Proactive Transmission of Replicated Frames

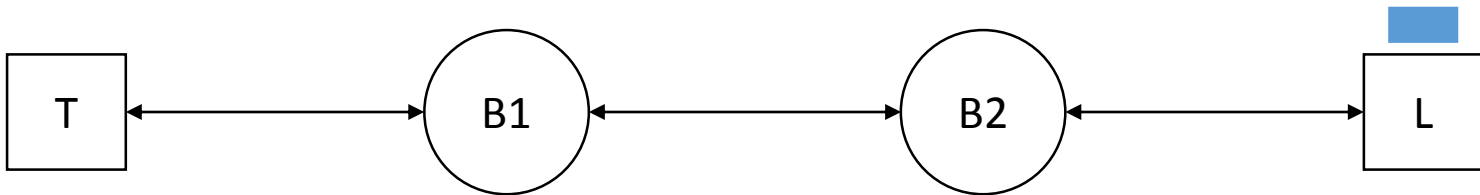
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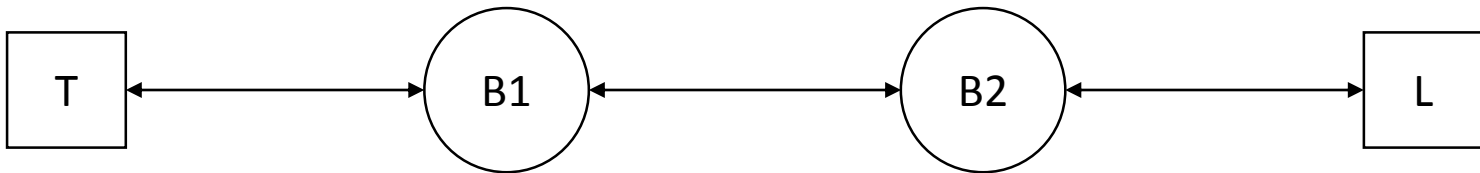
Proactive Transmission of Replicated Frames

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Proactive Transmission of Replicated Frames

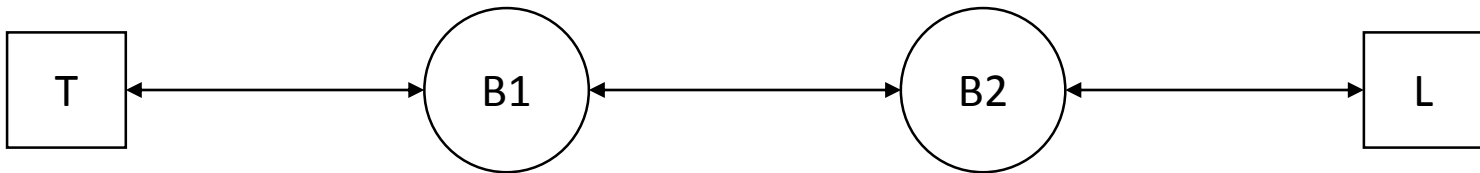
End-to-end estimation, link-based replication



Proactive Transmission of Replicated Frames

End-to-end estimation, link-based replication

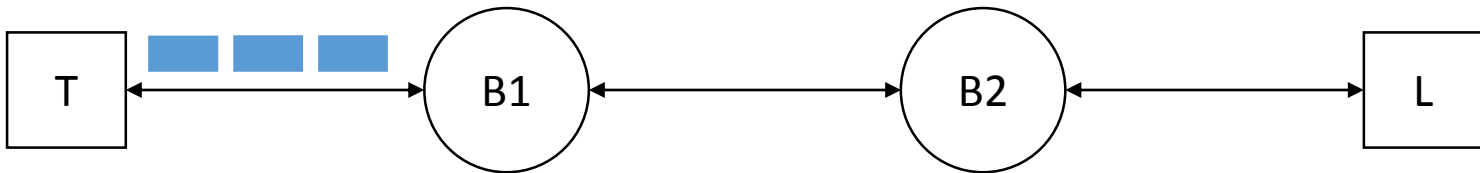
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Proactive Transmission of Replicated Frames

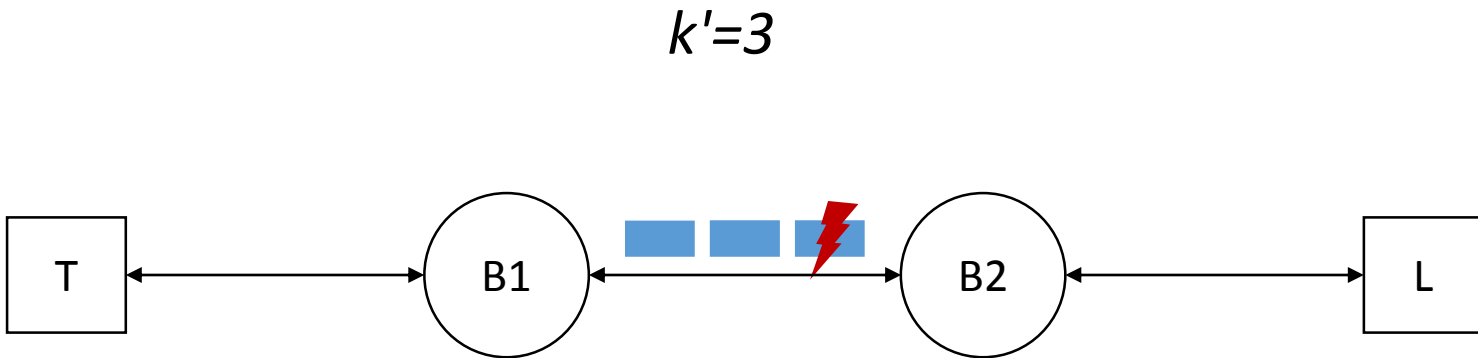
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Proactive Transmission of Replicated Frames

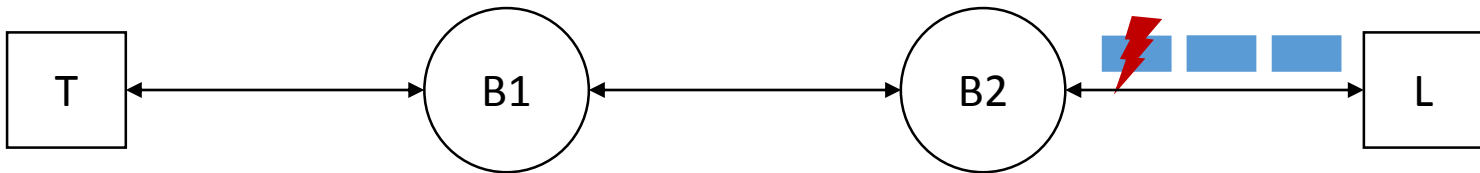
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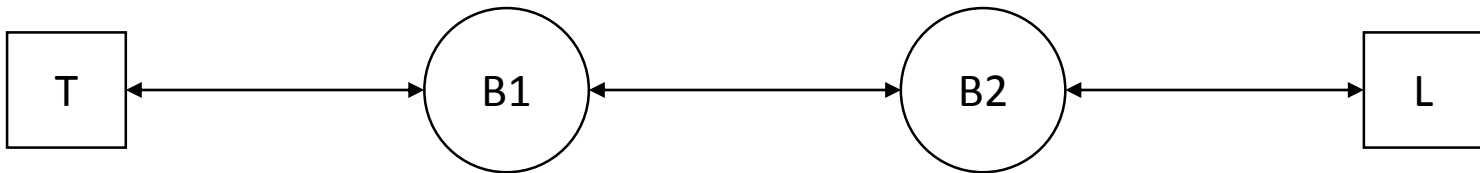
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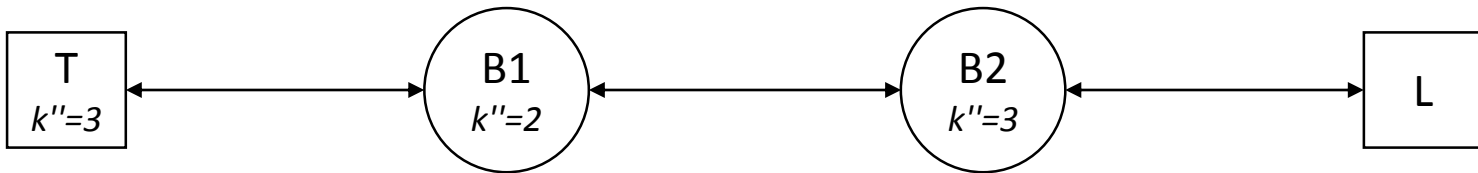
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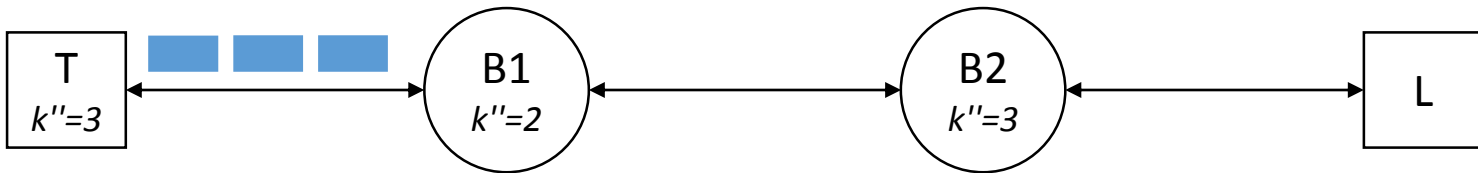
Proactive Transmission of Replicated Frames

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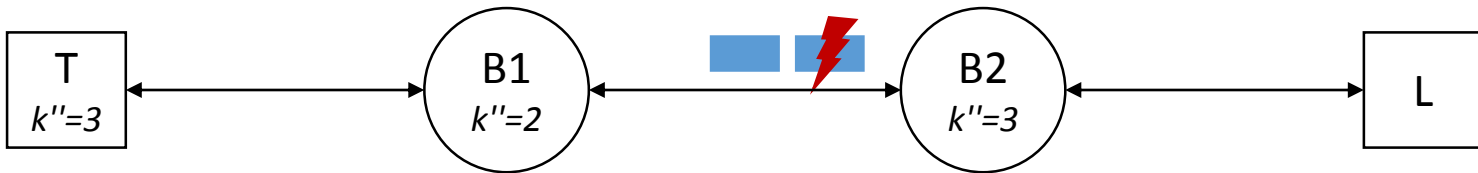
Proactive Transmission of Replicated Frames

Link-based estimation and replication



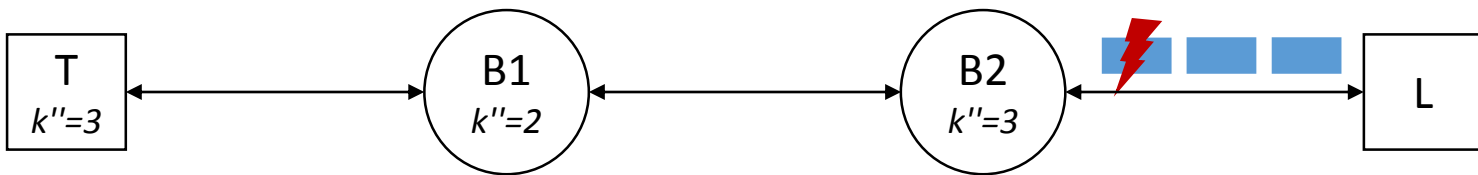
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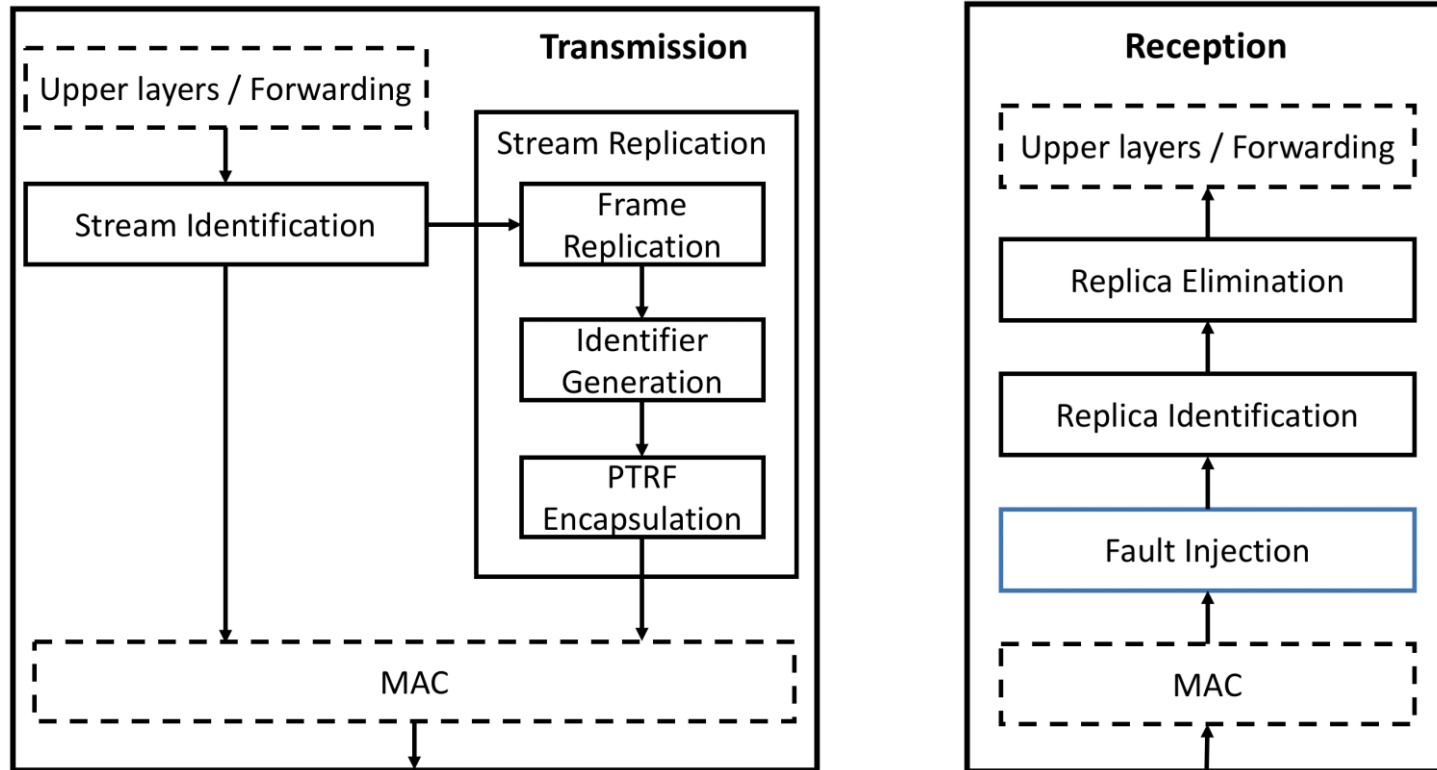


IN THIS WORK WE VALIDATE AND
COMPARE THE APPROACHES OF THE
TIME REDUNDANCY MECHANISM
THROUGH SIMULATION

OMNeT++ simulation model

- Implement the PTRF mechanism over OMNeT++.
- TSimNet model as starting point [1].
- Additions:
 - Creation of replicas.
 - Identification and elimination of replicas.
 - Frame structure specification.

OMNeT++ simulation model



Experiments

- We validated and compared the three approaches.
- We used exhaustive fault injection.
 - Inject all the possible combinations of frame losses.
- We used an automotive use case.
 - Study the behaviour of each approach in a realistic scenario.

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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.

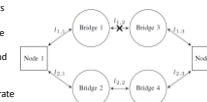


Problem

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.

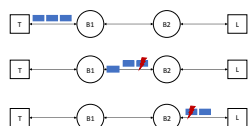


In this work we evaluate time redundancy through exhaustive fault injection and an automotive use case

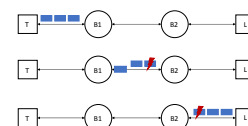
Proactive Time Redundancy

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

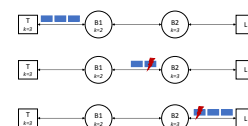
EZE estimation and replication of frames (A)



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

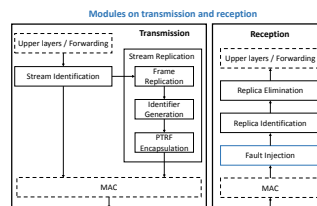


Link-based estimation and replication of frames (C)



OMNeT++ simulation model

We used simulation to evaluate and compare the proposed approaches.



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

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

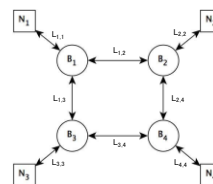
$$(A) \quad \begin{matrix} k-1 \\ \vdots \\ 1 \\ 0 \end{matrix} \quad \begin{matrix} k-1 \\ \vdots \\ 1 \\ 0 \end{matrix} \quad \begin{matrix} k-1 \\ \vdots \\ 1 \\ 0 \end{matrix} \quad \begin{matrix} k-1 \\ \vdots \\ 1 \\ 0 \end{matrix} \quad \begin{matrix} k-1 \\ \vdots \\ 1 \\ 0 \end{matrix} \quad \begin{matrix} k-1 \\ \vdots \\ 1 \\ 0 \end{matrix}$$

- 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

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

Results

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

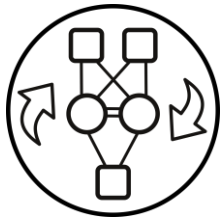
Approach	Traffic type	Exp. 1			Exp. 2			Exp. 3		
		Exp. 1	Exp. 2	Exp. 3	Exp. 1	Exp. 2	Exp. 3	Exp. 1	Exp. 2	Exp. 3
A	Control	0	4	2	0	0	0	0	0	0
	ADAS	0	8	2	0	0	0	0	0	0
	Video	24	148	176	0	0	0	0	0	0
	Audio	6	25	56	0	0	0	0	0	0
	Total	53	400	619	0	0	0	0	0	0
B	Control	0	2	0	0	0	0	0	0	0
	ADAS	1	8	0	0	0	0	0	0	0
	Video	17	163	173	0	0	0	0	0	0
	Audio	7	38	60	0	0	0	0	0	0
	Total	55	435	624	0	0	0	0	0	0
C	Control	0	2	1	0	0	0	0	0	0
	ADAS	1	3	5	0	0	0	0	0	0
	Video	23	142	172	0	0	0	0	0	0
	Audio	8	37	73	0	0	0	0	0	0
	Total	55	412	626	0	0	0	0	0	0

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

Questions?
Please meet me at the poster!





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