Mixing Time and Spatial Redundancy over Time Sensitive Networking

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Abstract

Cyber-Physical Systems (CPSs) usually execute critical applications, which imposed the use of specialised networks due to their high reliability and hard real-time requirements.
There is a growing interest in developing CPSs capable of **adapting** to unpredictable changes in the environment without jeopardising their correct operation.
Ethernet is an appealing technology to build the networks of future adaptive CPSs, due to the advantages in bandwidth, cost and internet compatibility offered.
Ethernet lacks real-time, reliability and flexibility services. Thus, the IEEE **Time-Sensitive Networking** task group are developing a set of standards (commonly referred to as TSN) to provide Ethernet with said services.
Nevertheless, TSN's reliability services are not enough for some highly-critical applications. Thus, we proposed a mechanism to tolerate temporary faults in the Layer 2 of TSN-based networks.
In this work we propose to mix time and spatial redundancy over a TSN-based network to increase its reliability while reducing resource consumption.

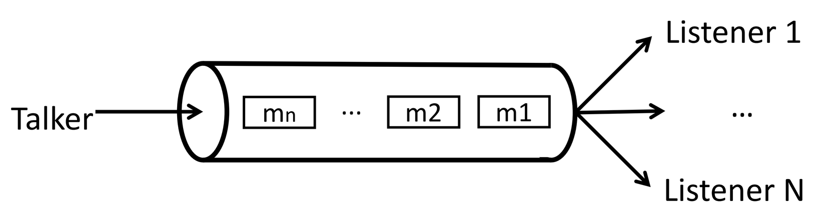
Time-Sensitive Networking Overview

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.



Time-Sensitive Networking Reliability

Three standards related to reliability:

- IEEE 802.1Qci: enables error containment. It allows to drop or assign new priorities to untimely frames or frames that exceed the bandwidth assigned to a given stream.
- IEEE 802.1Qca: describes new services, to allow for the creation of multiple and non-shortest paths between any pair of nodes and the further reservation of resources through those paths.
- IEEE 802.1CB: manages the replication of streams so one frame will be transmitted in parallel through each one of the multiple paths created by Qca. It defines how to **identify** streams that must be replicated, how frames should be **replicated at transmission** and **identified at reception**. Every element in the replicated paths, bridges and nodes, implement the replication and elimination mechanisms. This standard is called Frame Replication and Elimination for Reliability (FRER).

In this work we propose to mix time and spatial redundancy to efficiently tolerate transient and permanent faults of the channel

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 transient faults is not adequate:

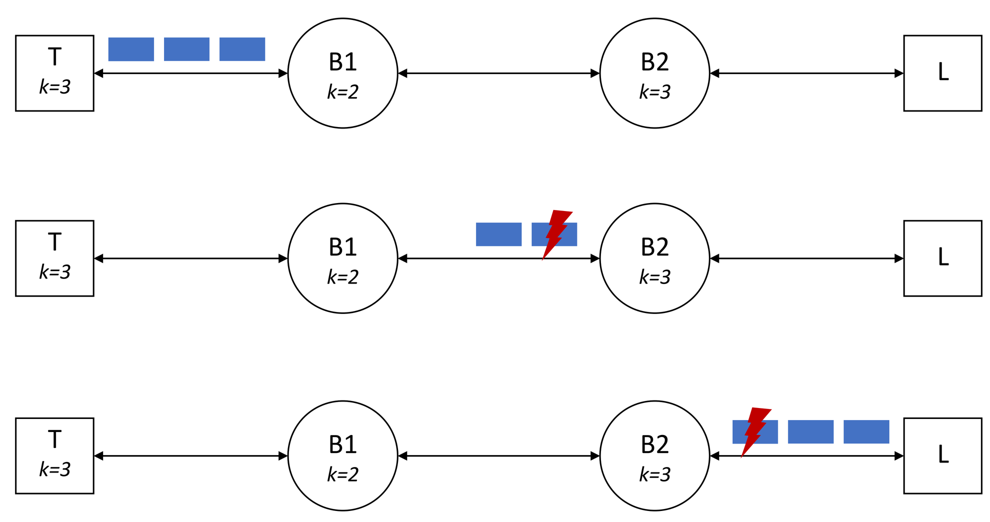
- The communication channel is specially vulnerable to transient faults.
- Spatial redundancy has high impact in the cost and size of the system.
- When permanent faults cause the attrition of the spatial redundancy, it may not be possible to tolerate transient faults any more.

We propose to mix proactive time replication with spatial redundancy to increase the reliability of the network in an efficient manner. We consider two scenarios:

- Highly critical networks that count with spatial redundancy.
- Mixed-criticality networks that do not count with spatial redundancy in all links.

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.



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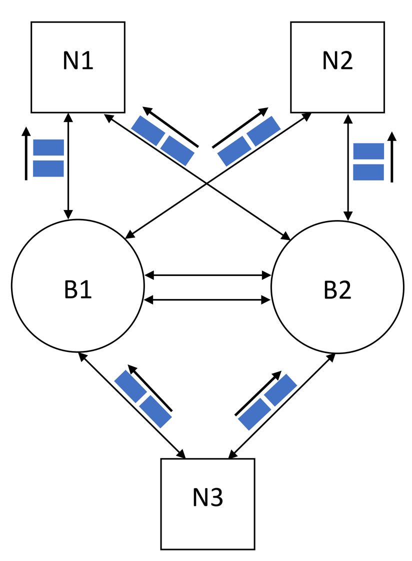
Highly critical systems



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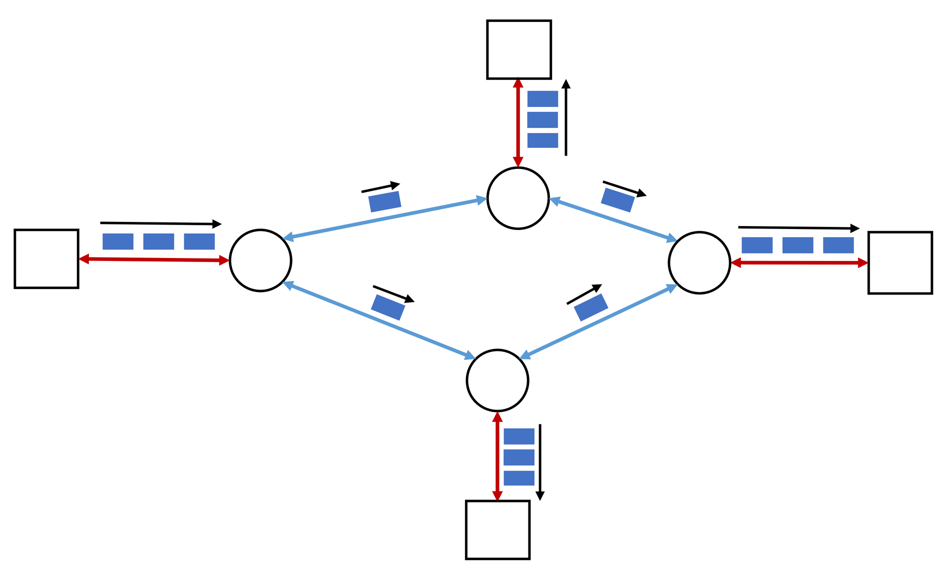
Proxy approach for FRER



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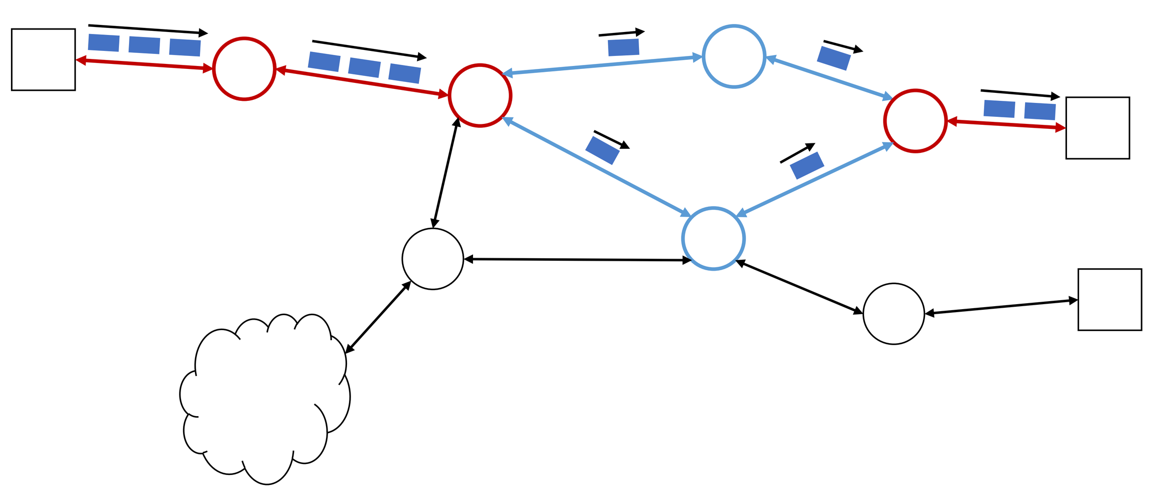
Unknown network architectures



Conclusions and Future Work

Conclusions:

- Spatial redundancy is not adequate to tolerate temporary faults as it is costly and non-efficient.
- Use proactive frame replication to tolerate temporary faults in the links.
- Mix time and spatial redundancy to achieve higher reliability in the network in an efficient manner:
  - Highly critical networks.
  - Spatial redundancy used in proxy mode.
  - Large unknown meshed networks.
- Need for additional mechanisms:
  - Detect non-redundant paths.
  - Configure adequate reliability.
  - Configure the network.
- Use a Centralised Network Architecture to carry out the configuration autonomously.

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