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

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ABSTRACT

Time-Sensitive Networking (TSN) is a set of technical standards that are being developed by the IEEE. These standards aim at providing Ethernet with network management, real-time and reliability services in the layer 2 of the network architecture. TSN is devised to provide adequate services to a great variety of systems, among which we can find Cyberphysical Systems (CPSs). CPSs are characterised by their interaction with the environment in which they are deployed. This interactions imposes strict requirements in terms of timeliness and reliability. Moreover, modern CPSs are expected to adapt to changes in the environment without interrupting or jeopardizing their correct operation. These adaptive CPSs require all the levels of the architecture to meet these demanding requirements, including the network.

Although TSN seems a promising technology to build the networks of future CPSs, there are some aspects not covered by the standards that need to be addressed [3]. Specifically, we find some reliability aspects that are important to meet the demands of critical applications. TSN provides spatial redundancy to transmit messages through several paths in parallel [1, 2]. Nonetheless, TSN does not provide any time redundancy mechanism in this level of the architecture specifically design to tolerate temporary faults in the channel.

Even though spatial redundancy can be used to tolerate temporary faults, on top of tolerating permanent ones, it is not a suitable solution for a series of reasons. First, permanent faults have a significant lower probability compared to temporary ones. Thus, using spatial redundancy to also tolerate temporary faults can increase the number of redundant paths needed to reach the adequate reliability; increasing the cost of the network too. Moreover, when permanent faults in the network cause the attrition of the redundancy it will no longer be possible to tolerate temporary faults, even in scenarios where time redundancy could.

Moreover, even though TSN can work with mechanisms to tolerate temporary faults in the links, such as those based on Automatic Repeat Request (ARQ) techniques, these are not suitable for real-time systems. This is so as ARQ-based solutions rely on the transmission of acknowledgement (ACK) or negative ACK (NACK) messages to trigger the retransmission of frames when these are lost. Thus, ARQ-based solutions are non-deterministic in terms of bandwidth used and the time required to complete the transmission. Moreover, the jitter introduced by these solutions is high, as the difference in the end-to-end delay of different frames has a high variability. Moreover, ACKs and NACKs can also be affected by temporary faults, which introduces new fault scenarios that need to be tolerated.

For these reasons, we proposed to use proactive frame replication to tolerate temporary faults in the links. That is, we proposed a mechanism to transmit several copies of each frame in a preventive fashion to ensure that at least one copy reaches the destination even in the presence of temporary faults. The mechanism we proposed is called Proactive Transmission of Replicated Frames (PTRF). In a previous work we presented two different design approaches of the PTRF mechanism.

In this work we present a third PTRF approach and we provide a detailed description of the mechanism. We also check the feasibility of our designs with the implementation of a simulation model on top of OMNeT++; on top of which we carried out two different experiments. First we validated the solutions through exhaustive fault injection and we compared the approaches in terms of number of error scenarios that each one can tolerate. Second, we simulated an automotive case study to compare the approaches in a more realistic scenario in terms of errors.

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2. REFERENCES

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