Opportunities and Specific Plans for Migrating from PRP to TSN in Substation Automation Systems

Mateu Jover, Manuel Barranco, Julián Proenza
Departament de Ciències Matemàtiques i Informàtica, Universitat de les Illes Balears, Spain
{mateu.jover, manuel.barranco, julian.proenza}@uib.es

Universitat de les Illes Balears

systems, robotics & vision

1. Abstract

Electrical substations are vital for the power grid, and Substation Automation Systems (SASs) have been employed to enhance substation functionality and safety. As the energy landscape evolves, substations face new challenges such as accommodating an increasing number of prosumers. Thus, SASs require a reliable substation communication network (SCN) capable of supporting real-time control and diverse applications. While Ethernet-based SCN technologies have emerged, they often fall short in meeting all requirements, including TCP/IP support, cost-effective fault tolerance, and managing traffic with different real-time demands. Time-Sensitive Networking (TSN) standards have shown promise in addressing these limitations by providing novel mechanisms. **In this paper we compare TSN with the Parallel Redundancy Protocol (PRP) demonstrating that TSN offers better functionality and efficiency. In the direction of designing a comprehensive TSN-based architecture for SASs' Distributed Control Systems (DCSs) we start here by proposing a roadmap for the fault tolerance aspects.**

2. Motivation

- The electrical substation is a fundamental asset in the power grid and the future Smart Grid.
- But substations must evolve to suit the Smart Grid.
- In particular, the Substation Automation System (SAS) must evolve to support smart automation and services, while guaranteeing correct operation and safety.
- SAS are supported by Distributed Control Systems (DCSs) that must allow the smart automation and services for the Smart Grid.
- A SAS relies on a DCS and its underlying Substation Communication Network (SCN).
- Ethernet based technologies have been used for SCNs, i.e., IEC 62439-3 Standard (namely HSR & PRP).
- But HSR and PRP have limitations to meet the requirements of Smart Grid substations.
- **TSN as an enabling technology to overcome those limitations.**

3. Comparison of Full Duplex Ethernet Based PRP and Time-Sensitive Networking

Attributes	Subattributes	Full Duplex Eth PRP	Time Sensitive Networking	Opportunities of TSN for SASs
Real-Time Comms.	Clock sync	One clock per LAN (IEEE 1588 - PTP)	1 clock for the whole system (802.1AS, gPTP)	Simpler clock management in the whole sys.
	MAC for RT Comms.	802.1Q priorities	802.1Q priorities, shapers (Qav, Qbv), preempt.	Native support of mixed RT. *(Converged net.)*
Fault Tolerance	Topology and redundancy efficiency	2 independent LANs, with similar topology	Single LAN with arbitrary topology	Topological flexibility, cost-efficient FT topology
		≤ 2 redundant paths can be used	Arbitrary level of redundant paths	≥2 redundant paths per frame to increase FT
	Routing	Only needs to consider RT/performance	Needs to consider also FT	None
	Red. manag. Granularity	(De)Duplication only in nodes	(De)Replication in nodes and bridges	Have more placing alternatives for (de)replication
	Reg. node FT connect.	Connection through specific HW (RedBox)	Direct connection via bridge	Eliminate HW bottleneck caused by RedBoxes
	Error containment	Only Eth corrupted frame dropping	Adds per-Stream Filtering and Policing (802.1Qci)	Restrict the failure semantics of the nodes
	Fault diagnosis support	Detection of omissions in nodes	Detection of omissions in bridges and nodes	Increasing availability/reliability with more precise fault diagnosis
Network Manag.	Configuration domains	Three: one per LAN, one for the nodes	Single config. domain (nodes and bridges)	Reduced configuration overhead
	Architectures for config.	None	Three architectures (nodes and bridges)	Less error prone configuration and opportunity to achieve seamless interoperation among configuration tools from different vendors
	Management profiles	Profiles just for clock synchronization	Enriched profiles for several aspects	

4. Roadmap for TSN into SAS (FT)

Real-Time and Net. Management aspects are out of scope

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Develop mechanisms to tolerate faults in the channel

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Develop mechanisms to tolerate faults in the nodes

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Integrate those mechanisms in a Fault Tolerant architecture

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Verification and validation of the Fault Tolerant architecture

5. Summary

- TSN offers many advantages to better meet the requirements of Substation Communication Networks (SCNs) for the Smart Grid.
- We have proposed a roadmap which focuses on providing a complete fault-tolerant TSN-based architecture for SASs.

6. Ongoing Work

- We have already started to work on:
  - Combining time and space redundancy
  - Designing cost-efficient topologies
  - Designing of a node replication scheme.

FT4TSNgrid

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