Analysis of the Side-Effects on Latency Bounds of Combinations of Scheduling, Redundancy and Synchronization Mechanisms in Time-Sensitive Networks

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The Patients Zero of the Research’s Virus

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Introduction

Analysis of the Side-Effects on Latency Bounds of Combinations of Scheduling, Redundancy and Synchronization Mechanisms in Time-Sensitive Networks

Public networks (e.g., the Internet) vs. Time-Sensitive Networks

Best-effort service vs. Deterministic Service

Bounded Latency + no loss by congestion

IEEE *Time-Sensitive Networking* (TSN)
IETF *Deterministic Networking* (DetNet)

Cyber-Physical Systems

Time-Sensitive Network

- Actuator
- Sensor
- Control unit

Safety-critical applications
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- Schedulers
- Traffic regulators
- ...

Scheduler mechanisms

- Literature
- Network Calculus

Bounded Latency

Observation frequency

Latency Bound Network Calculus

Deadline

Priority Scheduler

FIFO Scheduler

Regulator (Shaper)

High priority

Low priority

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Side-effects on Latency Bounds of Combinations of Mechanisms in TSNs

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Analysis of the Side-Effects on Latency Bounds of Combinations of Scheduling, Redundancy and Synchronization Mechanisms in Time-Sensitive Networks

• Schedulers
• Traffic regulators
• ...  

Bounded-latency mechanisms

New mechanisms and topologies

New services offered by time-sensitive networks

• Multi-path topologies
• Meshes, ...

Easy Reconfiguration

• Redundancy
• ...

High Reliability

• Synchronization protocol
• ...

Time Synchronization

Bounded Latency

Literature

Network Calculus

Literat.
Introduction

Analysis of the Side-Effects on Latency Bounds of Combinations of Scheduling, Redundancy and Synchronization Mechanisms in Time-Sensitive Networks

Bounded-Latency

- Schedulers
- Traffic regulators
- ...

Bounded-latency mechanisms

Literature

Network Calculus

Side effects?

New mechanisms and topologies

- Multi-path topologies
- Meshes, ...

Easy Reconfiguration

Literat.

High Reliability

Literat.

Time Synchronization

Literat.

New services offered by time-sensitive networks

- Redundancy
- ...

- Synchronization protocol
- ...

Literat.
Analysis of the Side-Effects on Latency Bounds of Combinations of Scheduling, Redundancy and Synchronization Mechanisms in Time-Sensitive Networks

Bounded Latency
- Schedulers
- Traffic regulators
- ...

Bounded-latency mechanisms

New mechanisms and topologies
- Multi-path topologies
- Meshes, ...

New services offered by time-sensitive networks
- Easy Reconfiguration
- High Reliability
- Time Synchronization

Side effects?

Literature
- Network Calculus

Literat.
The Plan:

- Multi-path topologies
- Redundancy (packet replication, duplicate elimination)
- Synchronization protocol (clock non-idealities in general)

Network-calculus models

Algorithms, analysis software
What Really Happened

- Multi-path topologies
- Redundancy (packet replication, duplicate elimination)
- Synchronization protocol (clock non-idealities in general)

Network-calculus models

Negative interactions, instability

Example: Cyclic dependencies

[Andrews 2009]: For all $\epsilon > 0$, there exists one FIFO network that becomes unstable at load $\epsilon$.

Solutions, Algorithms, analysis software xTFA
Network Calculus Relies on **Two Main Abstractions**

**Arrival Curve** $\alpha$

*upper-bounds the maximum amount of traffic* of the flow over any interval

**Service Curve** $\beta$

*lower-bounds the minimum amount of service* offered to the flow*

* Simplification

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Service-Curve Models

IEEE TSN mechanisms

A few years

flow $\alpha$ $\beta$

High priority
Low priority

Priority Scheduler

FIFO Scheduler

Interleaved Regulator

No service curve

Good service-curve model $\beta$