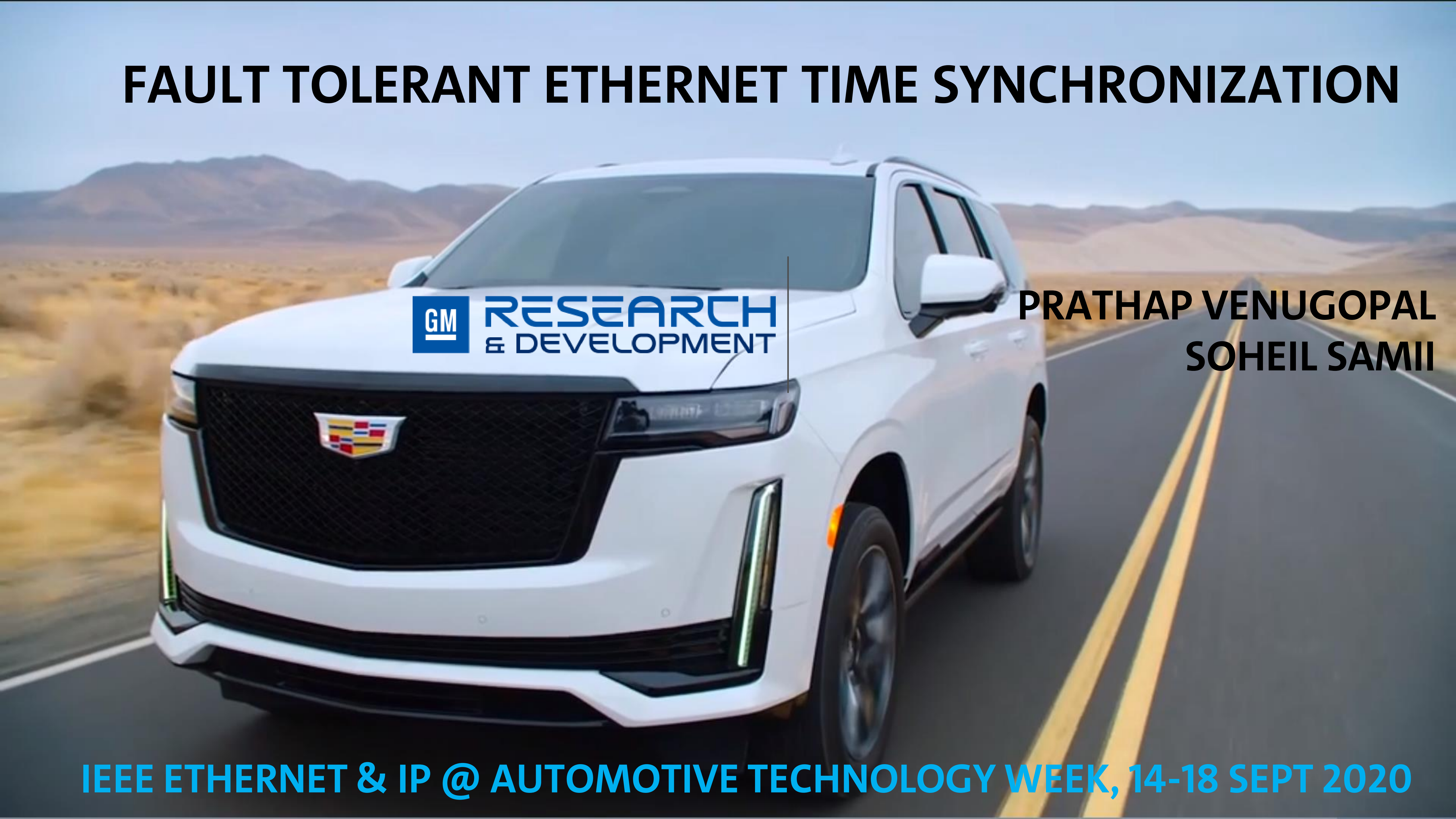

FAULT TOLERANT ETHERNET TIME SYNCHRONIZATION

GM RESEARCH & DEVELOPMENT

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IEEE ETHERNET & IP @ AUTOMOTIVE TECHNOLOGY WEEK, 14-18 SEPT 2020

AGENDA

- Need for Time Synchronization
- How is it done today?
- Challenges/Limitations for Fault tolerance in 802.1AS-2011
- Implementation of redundancy using 802.1AS-2020 & AUTOSAR
- TSN Automotive profile 802.1DG – How it helps
- Conclusion

INTRODUCTION

Time Synchronization:

Process of coordinating independent clocks in a system into a common time

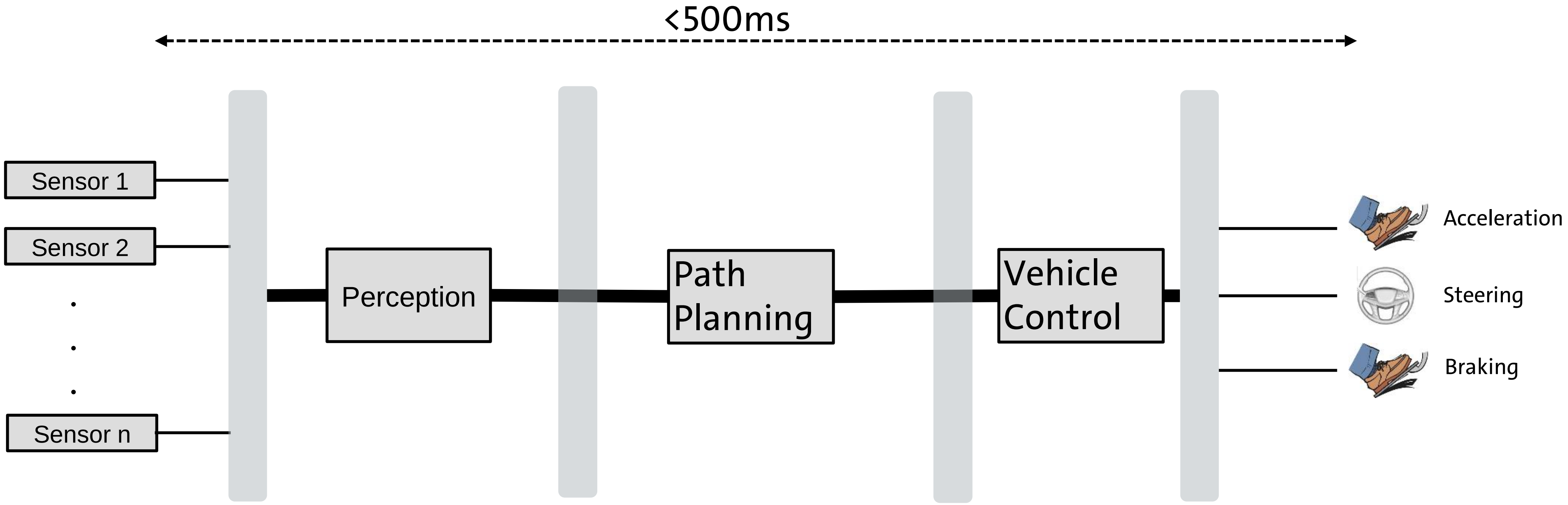
Benefits of Time Synchronization in ADAS and automated driving:

- Enables time stamping of sensor data for precise perception
- Enables synchronized sensor capture of environment which improves the precision and reduces the amount of computation needed in sensor fusion software
- Enables synchronized execution of application software clusters
- Having absolute time synchronization enables synchronized in-vehicle and sensing data from cloud and V2X/infrastructure-based sensors
- Timestamping state changes and error/event-logs helps in precise diagnostics

AUTOMATED DRIVING SYSTEM ENTITIES – TIME BUDGET

Reaction times:
Normal motorists : 500-750ms
Race car drivers : 200ms

- Worst case scenarios – e.g. Debris from the vehicle ahead / Cut-in scenarios
  - Vehicle traveling in **85mph (~137kmph)** would have travelled **62.3 feet (~20m)** within **500ms**

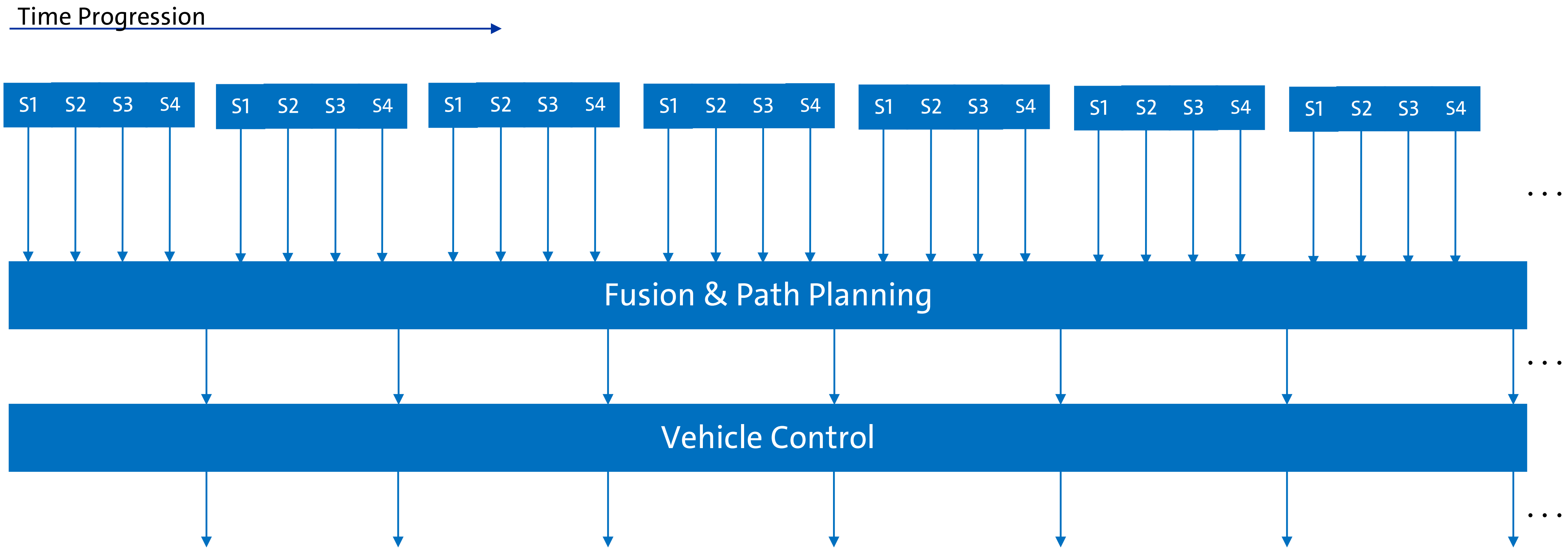


Automated driving systems needs to react faster (or equal to human reaction times) in the worst-case scenarios with complex environments

Comm. Channels (CAN/CAN-FD, LIN, Ethernet, LVDS, etc.), Network Devices (Switches, Gateway)

PCIe, SPI, etc

AD SYSTEM WITHOUT TIME SYNC



- Delays in perception during startup
- No synchronization in sensor capture
- No control in local drift
- No global notion of time
- Needs more computation in sensor fusion

HOW TIME SYNC ACHIEVED TODAY

Time sync achieved with one or a combination of

- Custom solutions
- Network Time Protocol
- IEEE 1588 (PTP)
- Local Time base (e.g. FlexRay)
- IEEE 802.1AS-2011 with Automotive AVNU profile
- IEEE 802.1AS-2011 with BMCA
- AUTOSAR Time Sync Protocol

Widely used today

WHY DO WE NEED FAULT TOLERANT ETHERNET TIME SYNCHRONIZATION?

- Synchronous sensing network and synchronous execution of tasks
- Even if synchronous sensing and execution is not used, software components like sensor fusion, which require time synchronization availability, need to be fault tolerant for certain automation levels and operational domains
- Future Electrical architectures that supports higher-automation level
  - Ethernet based backbone communication that will require time triggered traffic support as well
  - TSN technologies (e.g. 802.1Qbv, 802.1Qch) that support time-triggered traffic require uninterrupted, high-accuracy time synchronization

Fault-tolerant-time-sync is the foundation to support these needs

HOW TO MAKE TIME SYNCHRONIZATION FAULT TOLERANT

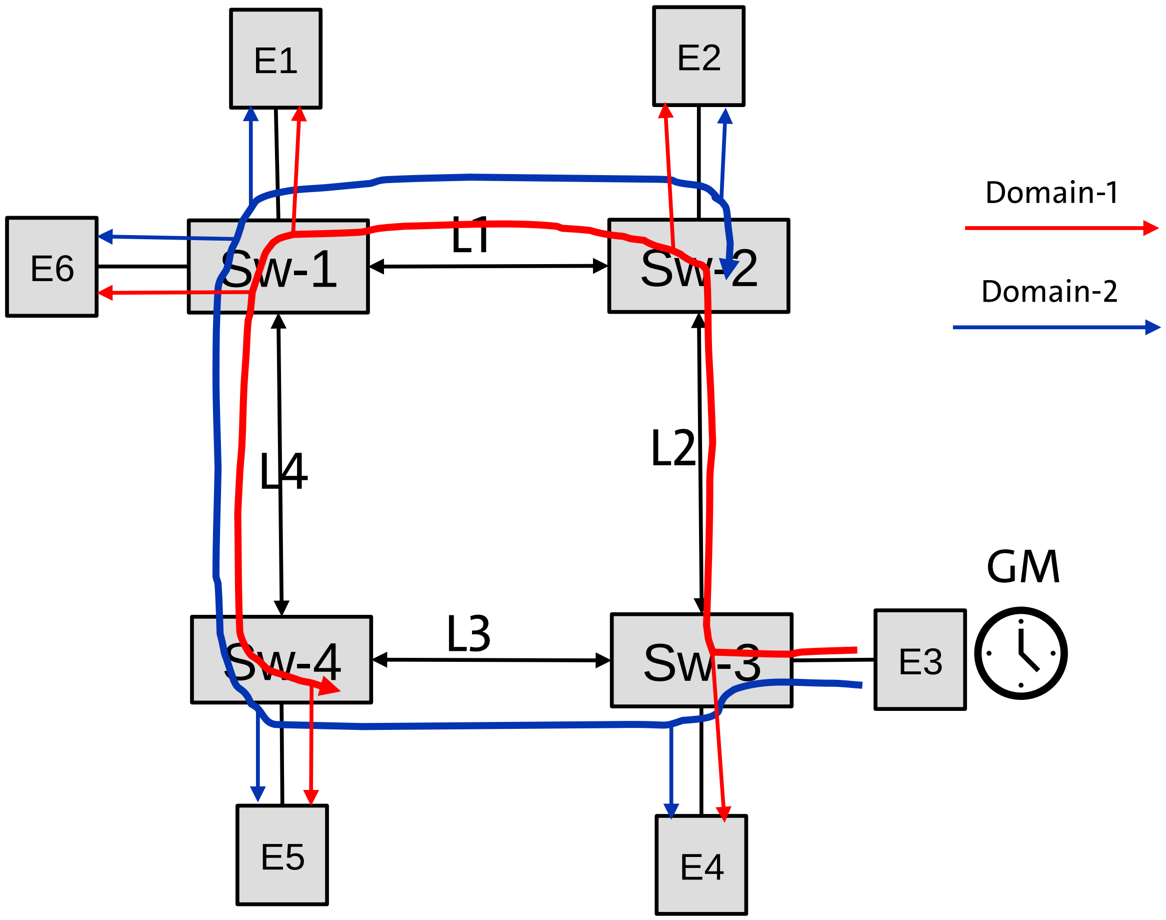
- Failures in time sync: Link failure, Grand Master failure or Grand master instability
- These can be addressed 802.1AS-2011 with BMCA enabled
  - With the following limitations:
    - No in-built mechanism for adjusting the time jump during Grandmaster failover
    - The process of running BMCA takes multiple seconds (in a bench experiment, 2.5-3 seconds per link).
      - e.g. for a network with 5 level clock tree, it would take 15 seconds for failover, a local clock with 100ppm would have drifted by 1.5 msec.

802.1AS-2020 addresses these challenges

ADDRESS LINK FAILURES

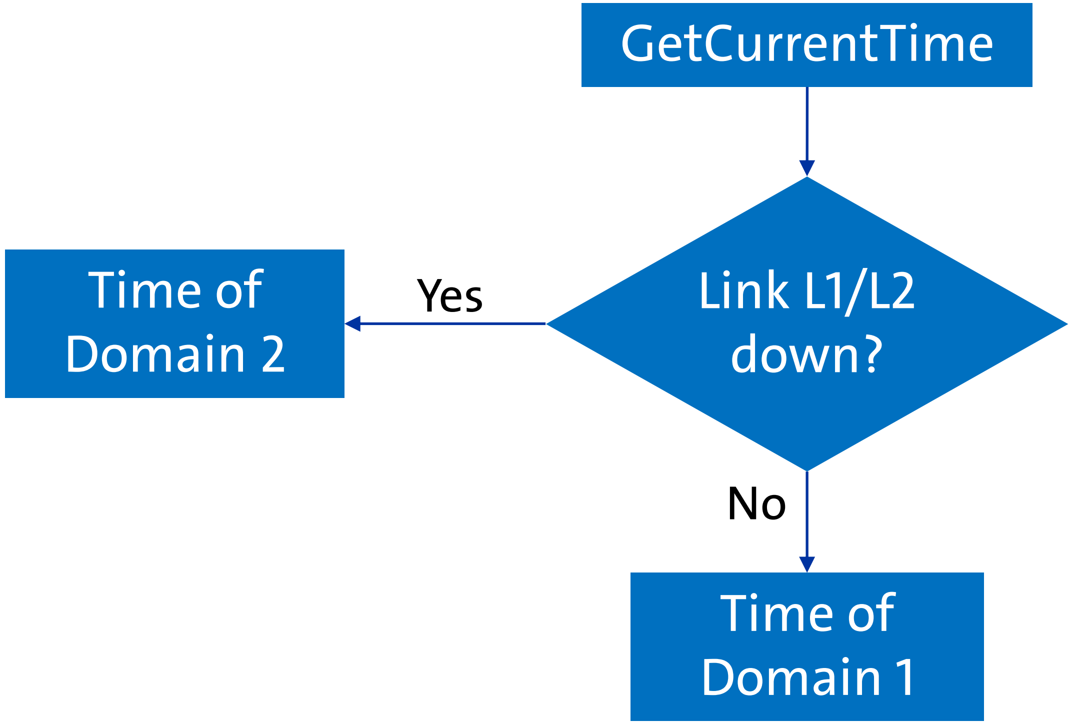
- Introduction of multiple time domains and configuring accordingly helps in recovering from link failures.
- Each end point should have the logic to deal with redundant domains
  - AUTOSAR based Synchronized Time base Manager

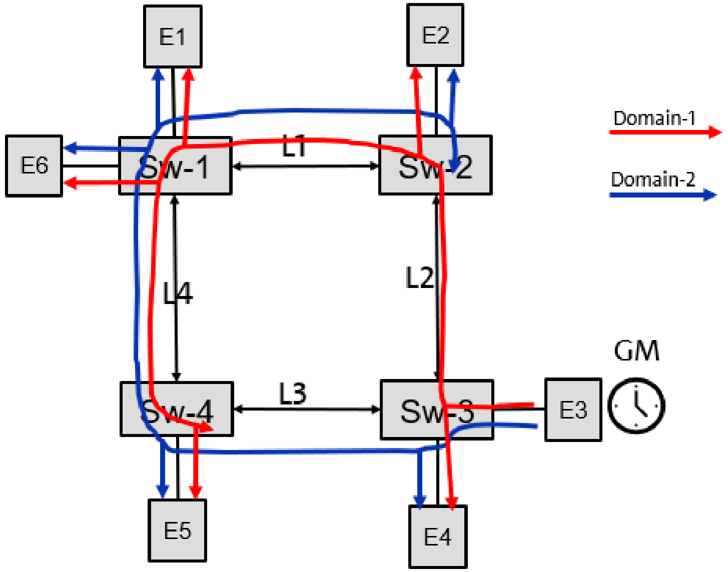
Sample implementation with one GM and two clock domains



HOW TO ARBITRATE

- In case of Link L1/L2 failure in this example, end point E1 can have the following logic implemented in its software



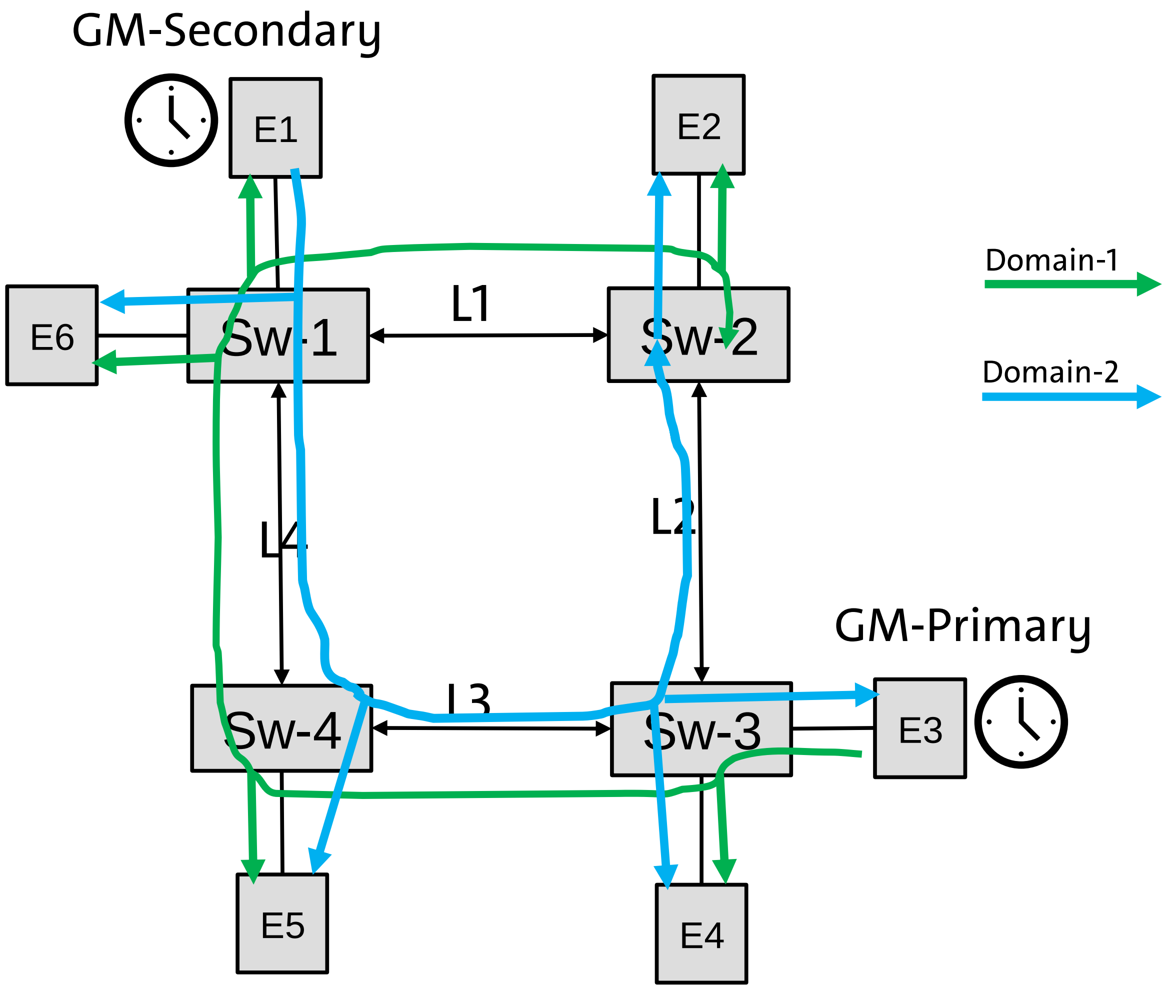


Similar logic could be implemented for any end points and its failure modes

ADDRESS GRAND MASTER FAILURE

- Back-up Grand Master(s) can be configured with domains in addressing Grand master failure
- Synchronizing primary and secondary Grand Master's clocks avoid time-jumps during switch over
- Each end point should implement the logic to deal with redundant domains
    - AUTOSAR's Synchronized Time base Manager
- In this way, the end points could have almost no failover time

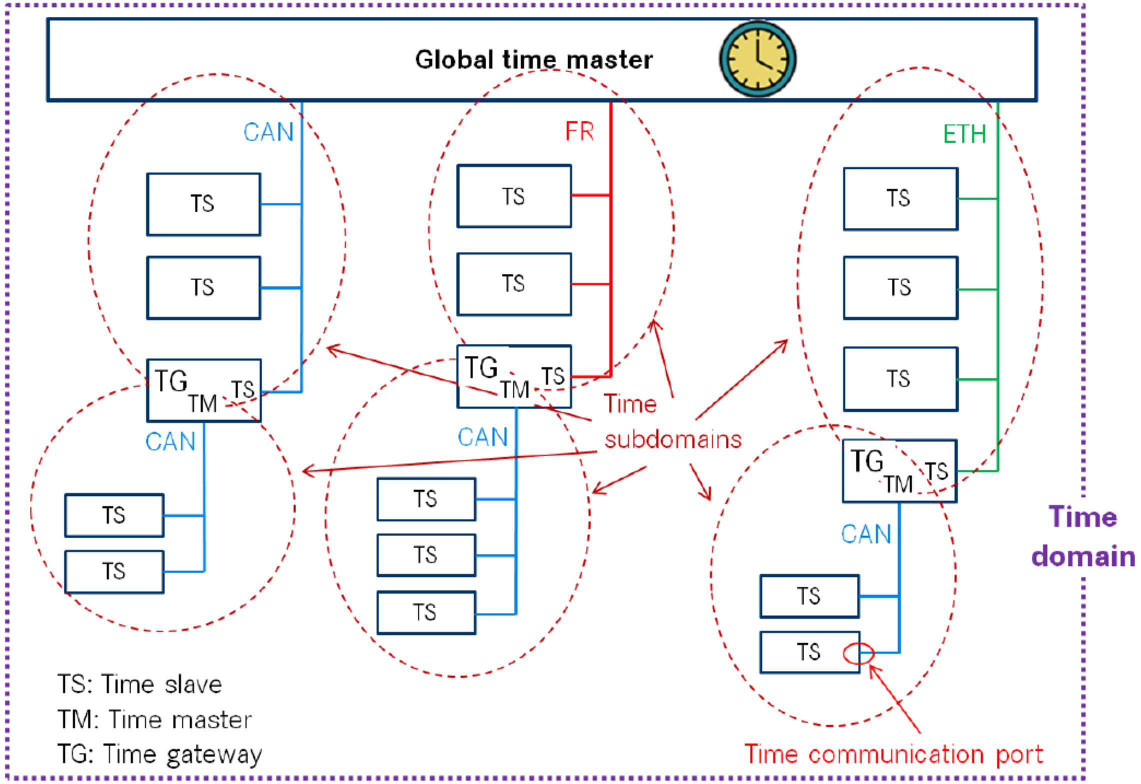
Sample implementation with two GMs with one clock domain each *



* More configurations possible

TIME SYNCHRONIZATION IN AUTOSAR

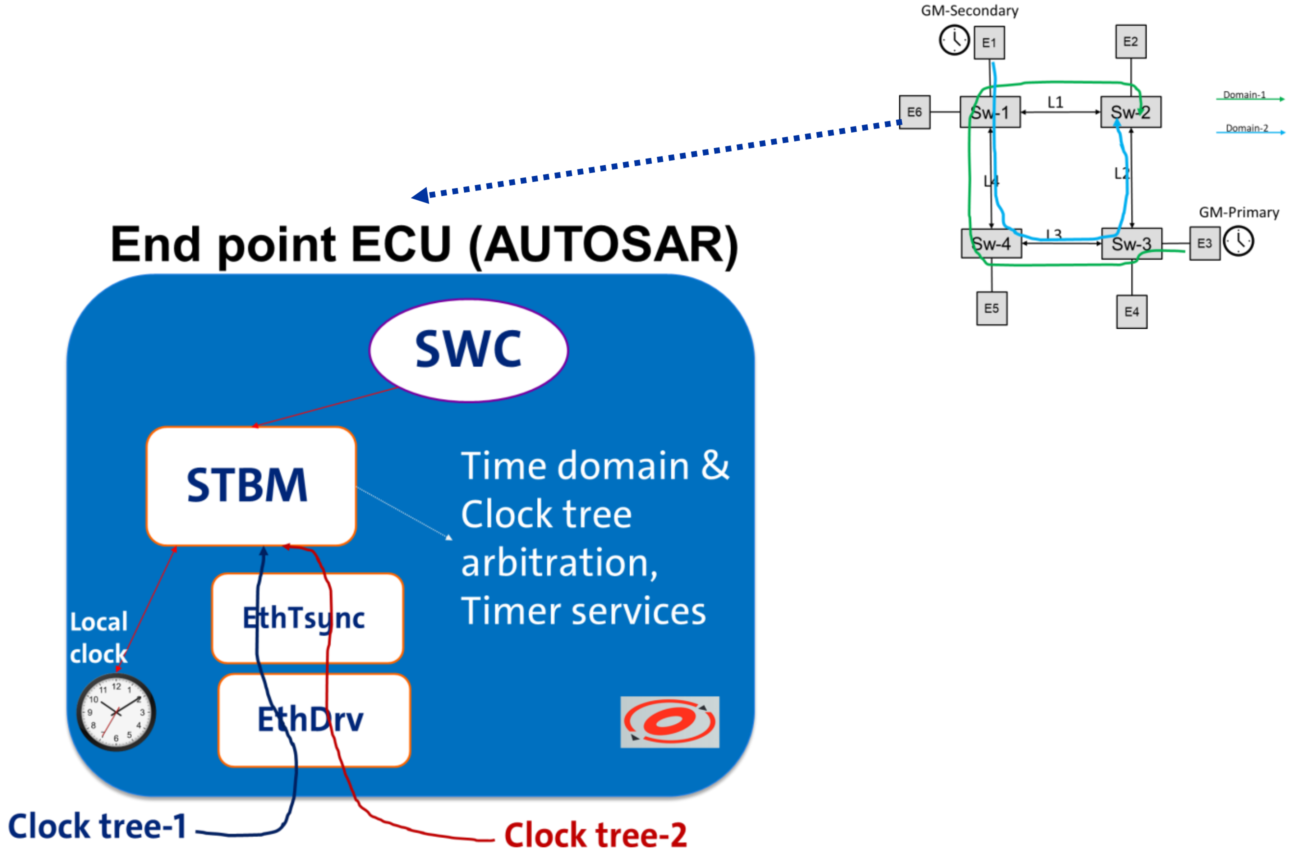
- Based on 802.1AS-2011
- No BMCA
- Time Synchronization Extensions
  - AUTOSAR Time Sync mechanisms extensions (TLV)
  - Checksum support
  - VLAN Tag support
  - Multiple time domains support
  - Time sub-domains
    - Extends time sync over CAN & FlexRay with Time Gateway



Reference: Time Synchronization Protocol Specification - AUTOSAR FO Release 1.5.0

ARBITRATION OF THE CLOCK TREES AT END POINTS

- Preliminary analysis indicates Synchronized time base manager's Timing slave could be used to arbitrate / switch between time domains
- Detailed study is ongoing if the current version of Time Sync Protocol and STBM requires any extension to support 802.1AS-2020



STBM – Synchronous time base manager
EthTsync – Ethernet Time Synchronization
EthDrv – Ethernet Driver
SWC- Software Component

802.1DG TSN AUTOMOTIVE PROFILE

802.1DG is underway and already has created ‘Base’ and ‘Extended’ profiles

For high level of automation, ‘Extended’ profile seems promising; it supports multiple time domains, which is the foundation for fault tolerant time synchronization

Table 14-1—Base profile TSN features

TSN FEATURE DESCRIPTION	REFERENCE	VALUE
Timing and Synchronization (gPTP) (IEEE Std 802.1AS)		Yes
Use External Port Configuration?	Annex E.3.1	Yes
Use BMCA?	Annex E.3.1	Optional
Send Announce messages whether using BMCA or not?	Annex E.3.1	Yes
Send Pdelay messages?	Annex E.3.2	Yes
Sync message format?	Annex E.3.3	Two-step
Maximum number of Domains?	Annex E.3.5	1
Message rates?	Table E-2, Annex E.3.4	Default values

Table 14-2—Extended profile TSN features

TSN FEATURE DESCRIPTION	REFERENCE	VALUE
Timing and Synchronization (gPTP) (IEEE Std 802.1AS)		Yes
Maximum number of Domains?	Annex E.3.5	2
Configure message rates via *Message interval request* signaling messages?	Table E-2,	Yes

Source: IEEE P802.1DG/D1.2

SUMMARY

- IEEE 802.1AS-2020 provides seamless redundancy for time synchronization in Ethernet based electrical architectures; IEEE 802.1DG Automotive TSN profile shall call out appropriate usage of its features and associated TSN technologies
- End points should be capable of both Time-Synchronous execution and clock domain arbitrations during grand master failover. AUTOSAR based Time Sync provides this capability, which vendors may adopt for end points.

CONCLUSION

- Fault-tolerant-time-sync is the foundation for higher level automated driving systems
- IEEE 802.1AS-2020 together with AUTOSAR based end points recommended for higher level of automated driving systems with complex driving domain
- IEEE 802.1DG profiling will help in choosing the right TSN protocol suite for the right level of automated driving

Thank you!


Auto Lane Change
Changing Lanes
166mi
RPMx1000
MPH
215mi
RADIO
99.3