Timing in Autonomous Vehicles

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Workshop on Synchronization & Timing Systems
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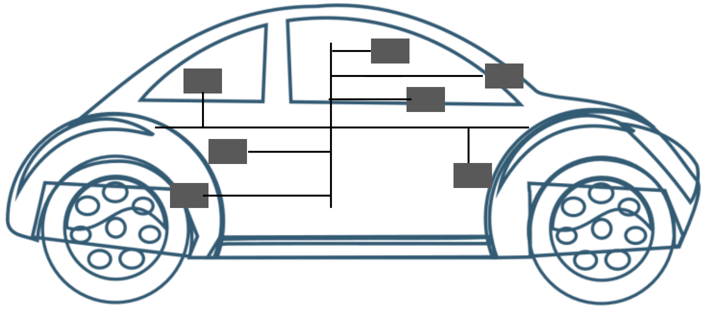
Outline

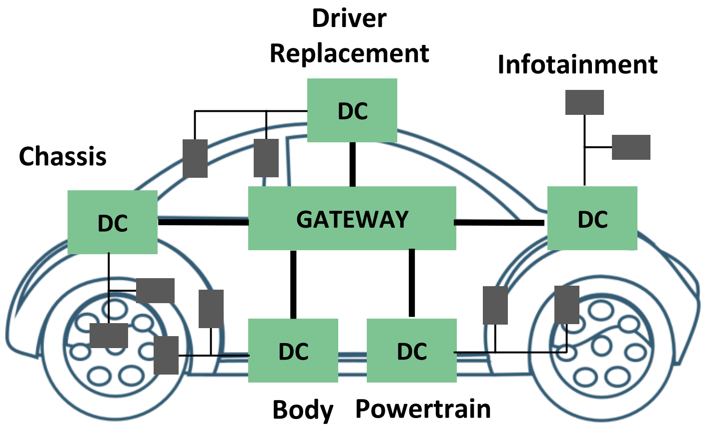
1. Autonomous Vehicles – Do we need them?
2. Vehicular Time/Sync Use Cases
3. Key Enabling Technologies
4. Vehicular Time/Sync Implementation
5. Standardization and Industry Groups

Vehicle Architecture Evolution

YESTERDAY

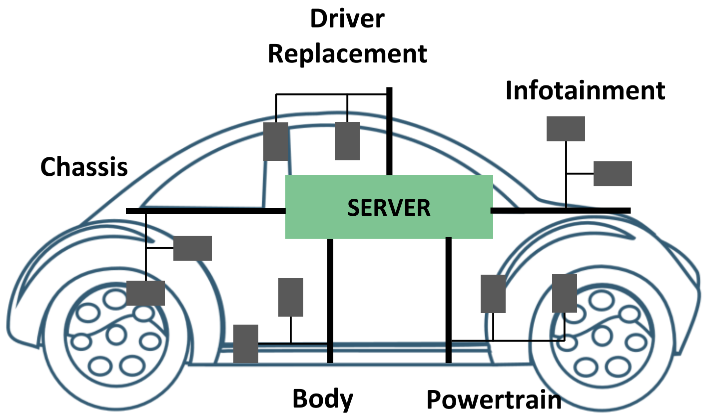


TODAY



DC = Domain Controller

TOMORROW



Dramatic Changes in Vehicle Architecture!

- Distributed architecture
- Manual control
- Low data rates (Kb/Mb)

- Domain centric
- Network connectivity
- L1, L2, L3 autonomy (ADAS)
- High data rates (Gb)

- Centralized architecture
- L4, L5 autonomy
- V2X communication
- Higher data rates (Gb/Tb)

Key Drivers for Autonomous Vehicles

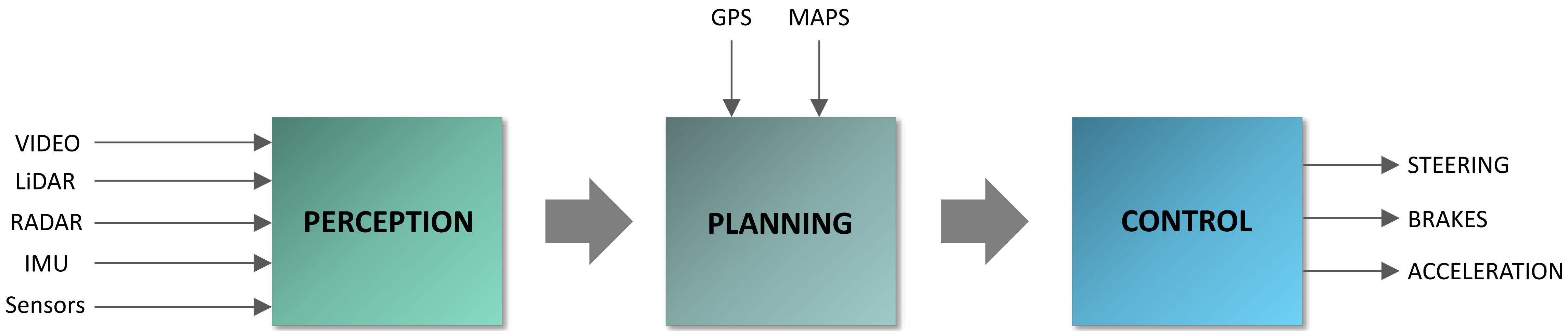
- In 2017, there were 37,000+ deaths due to road accidents in the US alone
- Driver error cited as reason in 94% of cases
- Economic cost to society: upwards of $830B

- Travelers stuck in their cars for nearly 7 billion extra hours
- $160B annual cost due to congestion

- Traffic congestion caused drivers to waste more than 3 billion gallons of fuel
- Connected vehicle environmental applications will give motorists the real time information they need to make “green” transportation choices

Autonomous vehicles will make roads safer, reduce traffic congestion and improve productivity

Autonomous Vehicles – Building Blocks



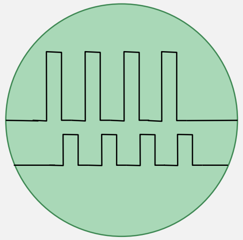
- Road surface detection
- Lane detection
- Road paint detection
- Pedestrian movement detection and prediction
- Position detection

- Route planning
- Motion path planning based on
  - Current position
  - Destination
  - Objects in Field of View

- Send commands to actuators to start or stop motion

Key Use Cases for Vehicular Time/Sync

FREQ/PHASE SYNC



Synchronization of runnable entities (functions)
An arbitrary number of functions must be executed synchronously (either at the same time or with a synchronized time offset)
Example: Sensor data read out and synchronous actuator triggering for ABS

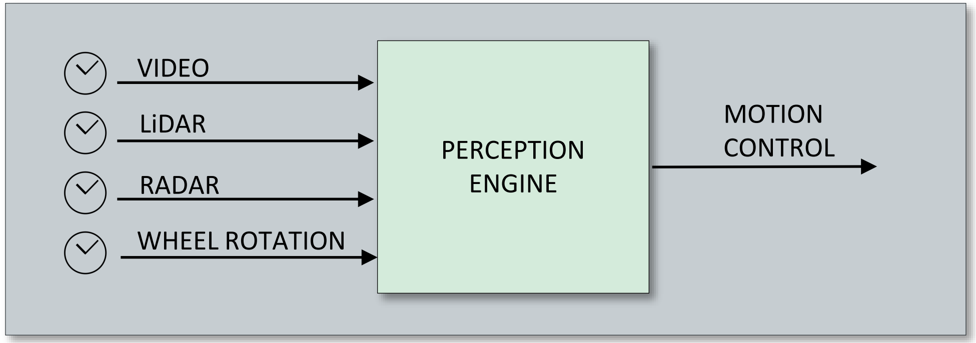
LOCAL TIME BASE

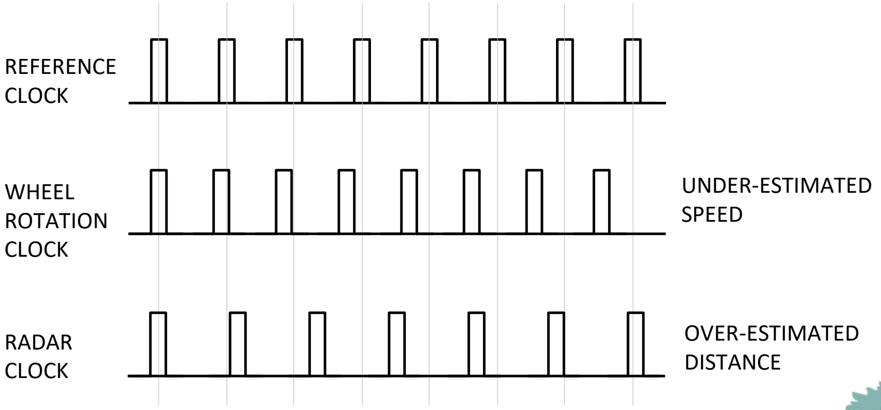
Sensor data fusion
Critical for proper correlation of data from various sensors, video cameras, LiDAR, etc.
Essential for localization and mapping functions

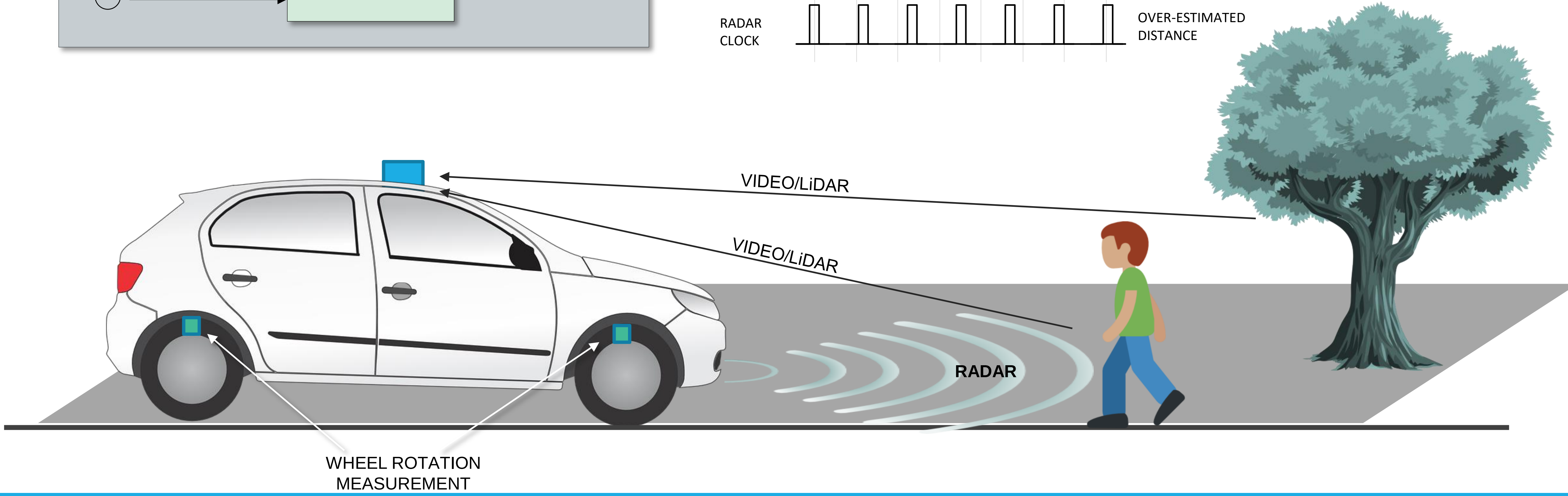
GNSS/UTC SYNC

V2V Communication
A UTC-referenced time base is essential for vehicle-to-vehicle communication
Event data recording
For temporal correlation of events and states (Ex. During an accident)
Access to synchronized calendar time for diagnostics and event logs

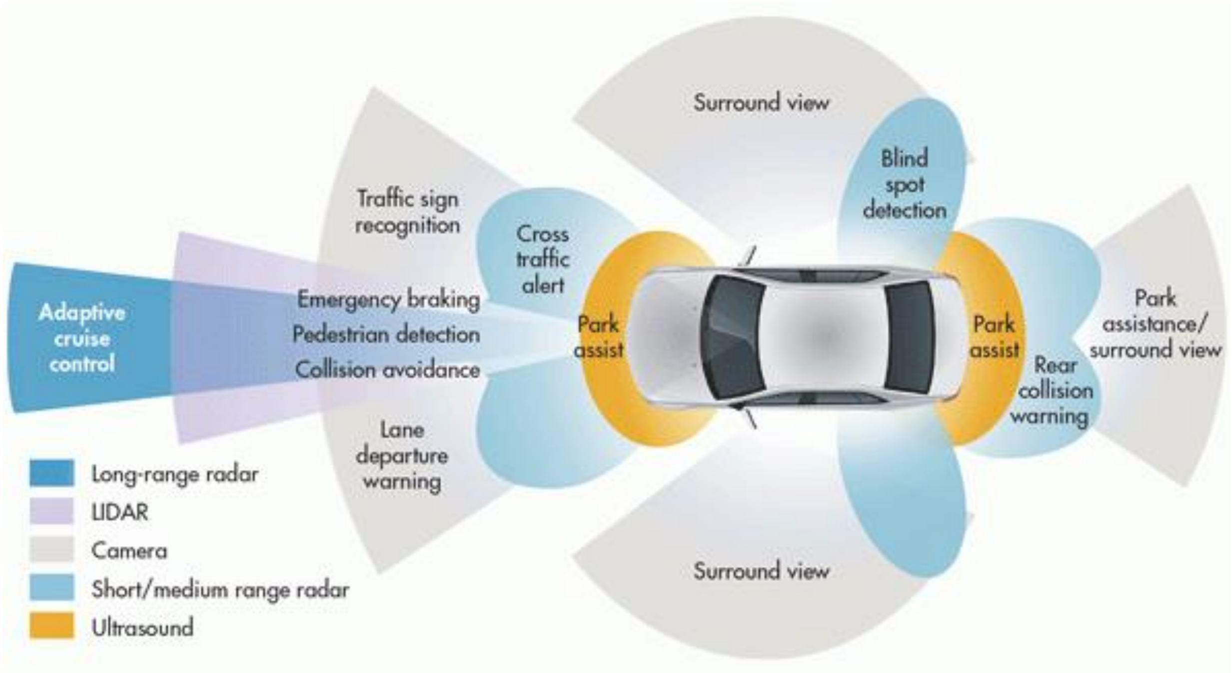
What Happens in the Absence of Sync?







Key Technologies - Sensor Fusion



Automated vehicles use about 30-40 sensors

- Proximity sensors, parking assist, blind spot detection, etc.

360° vision implemented using six or more video cameras

Information from various sources is combined or fused together to provide intelligent vehicle control

Required sync accuracy between sensors: 1 ms – 10 ms

Key Technologies – Vision Processing

Identification of objects in the vicinity of the vehicle

Recent advances in Machine Learning play a key role in vision processing

- Edge-detection and Object classification using Convolutional Neural Networks
- Fusion of data from Video images, LiDAR and RADAR
- Frame comparison to determine direction of motion

Cameras are typically 480p, 1080p or 4K resolution

- 30 frames-per-second or slower

Fusion of Video and LiDAR Images

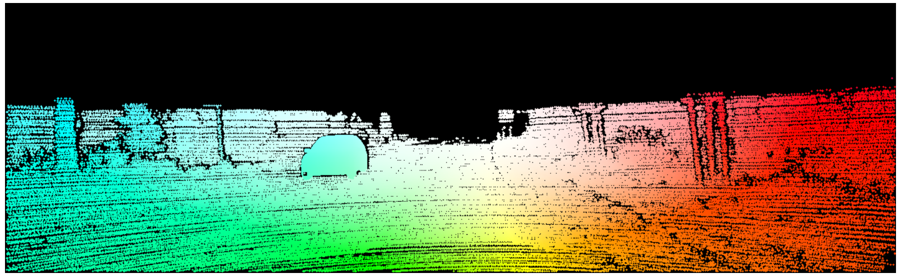
Video Camera

GPS Receiver

LiDAR

2011-09-26 14:14:10.918055936
2011-09-26 14:14:11.021768192
2011-09-26 14:14:11.125032704
2011-09-26 14:14:11.228328704
2011-09-26 14:14:11.331776512
2011-09-26 14:14:11.435280384
2011-09-26 14:14:11.538697728
2011-09-26 14:14:11.641968384
2011-09-26 14:14:11.745279232
2011-09-26 14:14:11.851740928
2011-09-26 14:14:11.952009472
2011-09-26 14:14:12.055380480
2011-09-26 14:14:12.158768128
2011-09-26 14:14:12.262141696
2011-09-26 14:14:12.365544704
2011-09-26 14:14:12.468922112
2011-09-26 14:14:12.572443904
2011-09-26 14:14:12.676016384
2011-09-26 14:14:12.779176192
2011-09-26 14:14:12.882682624
2011-09-26 14:14:12.986104832
2011-09-26 14:14:13.089569024

Timestamps are accurate to a nanosecond, but millisecond accuracy is sufficient for fusion of video and LiDAR images



2011-09-26 14:14:10.924614488
2011-09-26 14:14:11.024620889
2011-09-26 14:14:11.124700931
2011-09-26 14:14:11.224622334
2011-09-26 14:14:11.334622347
2011-09-26 14:14:11.434671024
2011-09-26 14:14:11.534665769
2011-09-26 14:14:11.644703857
2011-09-26 14:14:11.744622333
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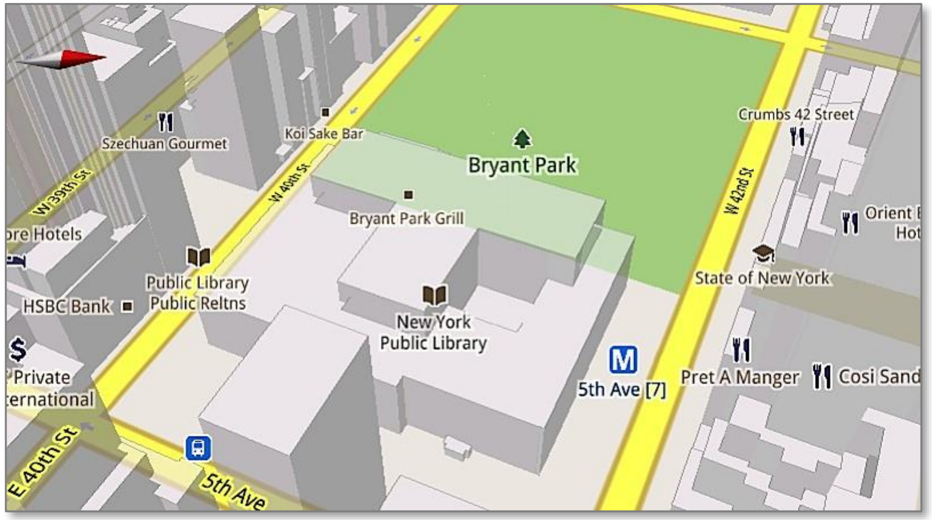
2011-09-26 14:14:12.774655721
2011-09-26 14:14:12.884699207
2011-09-26 14:14:12.974692026
2011-09-26 14:14:13.094868126

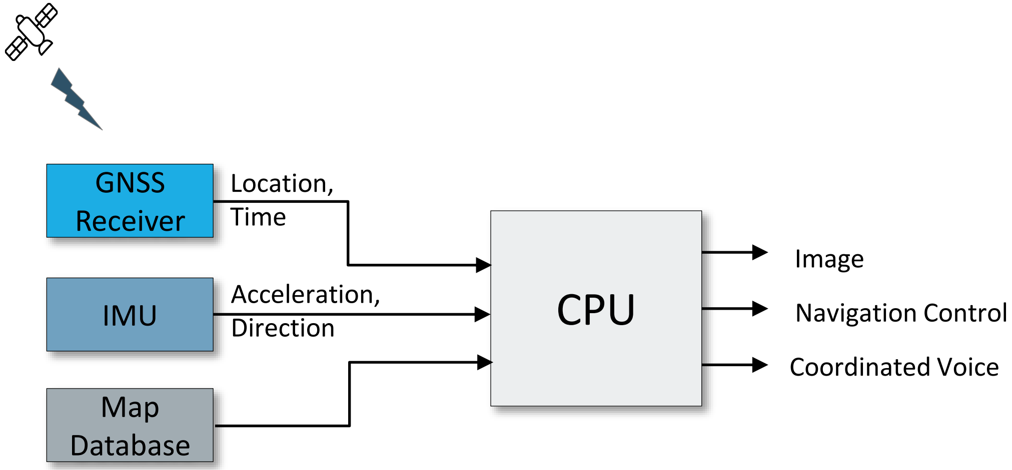
Key Technologies – Mapping and Navigation

Mapping enables precise location and the ability to navigate through streets and highways

- GNSS – general location awareness (within several meters)
- Cameras – identification of road markings, lane position and roadside beacons
- Detailed maps – position of roads and landmarks
- IMU – direction of motion and acceleration

The current position of the vehicle is gathered by correlating GNSS signals, IMU measurements, Map data and landmarks





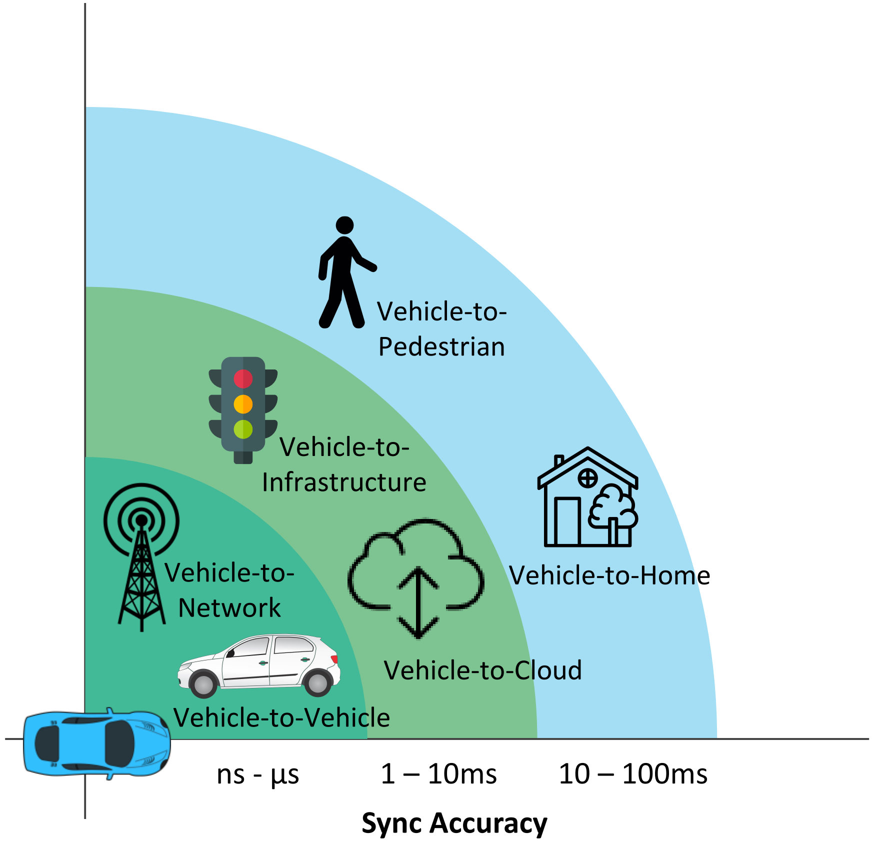
Key Technologies – V2X Communication

Vehicles can communicate with other vehicles, roadside infrastructure, pedestrians, and other “things” (‘X’ means ‘Everything’)

U.S. NHTSA has proposed requiring V2X in all new cars in four years

Current technologies in use:

- C-V2X - 802.11p standard in dedicated 5.9 GHz band
- DSRC
- LTE or 5G as an alternative approach



Required sync accuracy ranges between 100ns and 100ms depending on the application

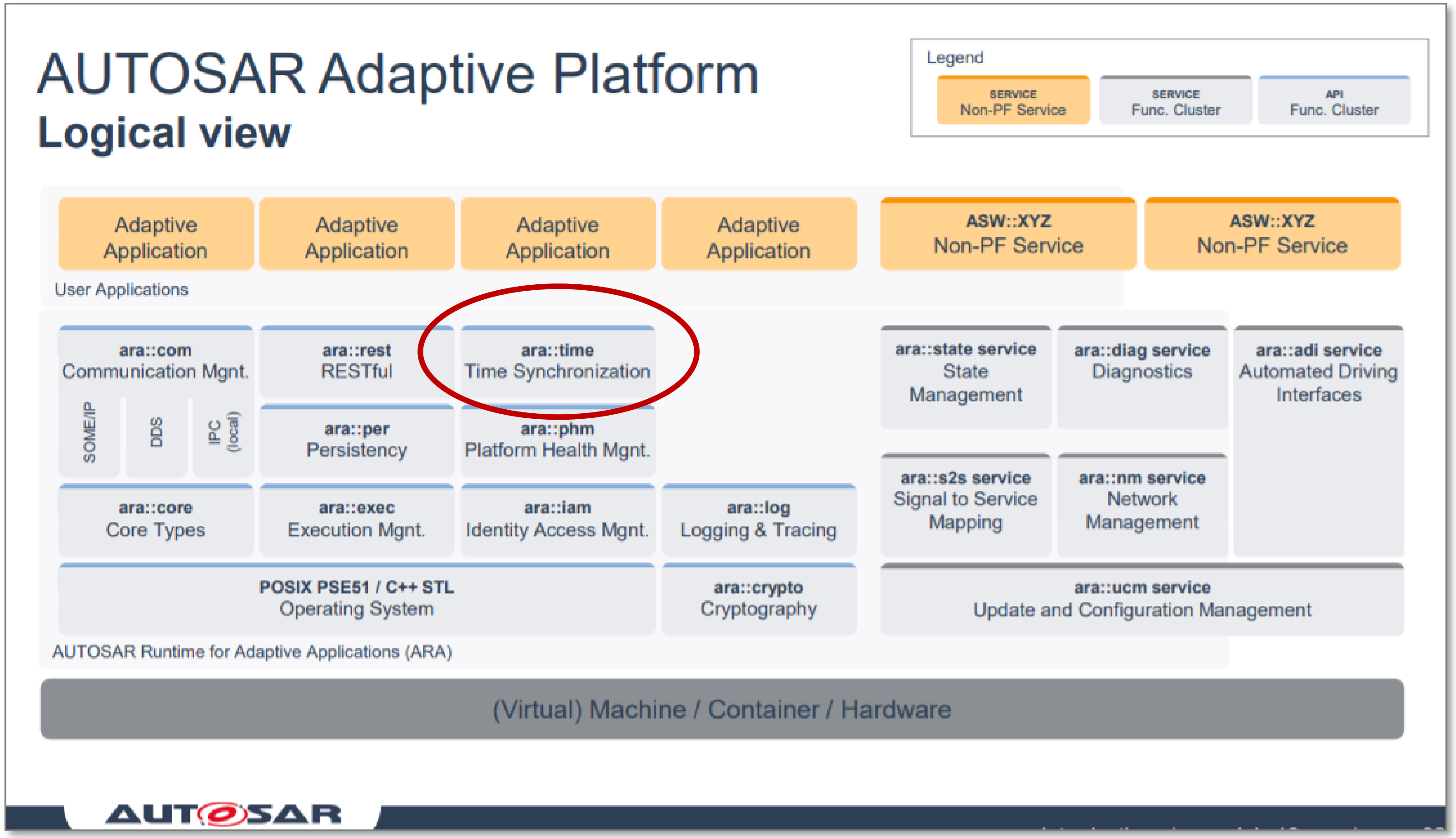
AUTOSAR – Open Automotive Architecture

AUTOSAR is the collaborative effort of auto makers, suppliers and software companies to standardize automotive software architecture

9 CORE MEMBERS

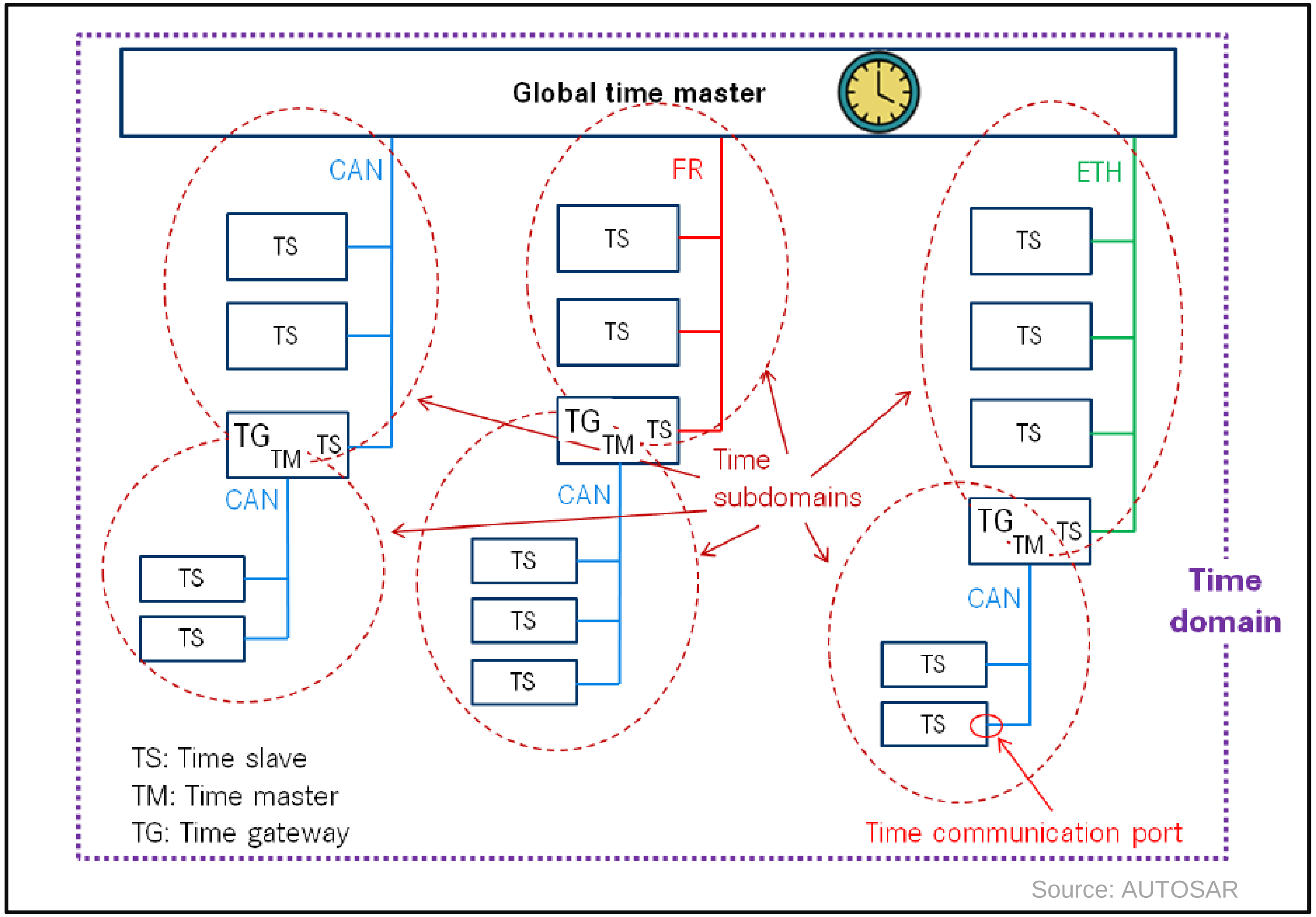
BMW Group
BOSCH
Continental
DAIMLER
Ford
GM
TOYOTA
PSA GROUPE
VOLKSWAGEN AG

80+ INDUSTRY PARTNERS



Source: AUTOSAR

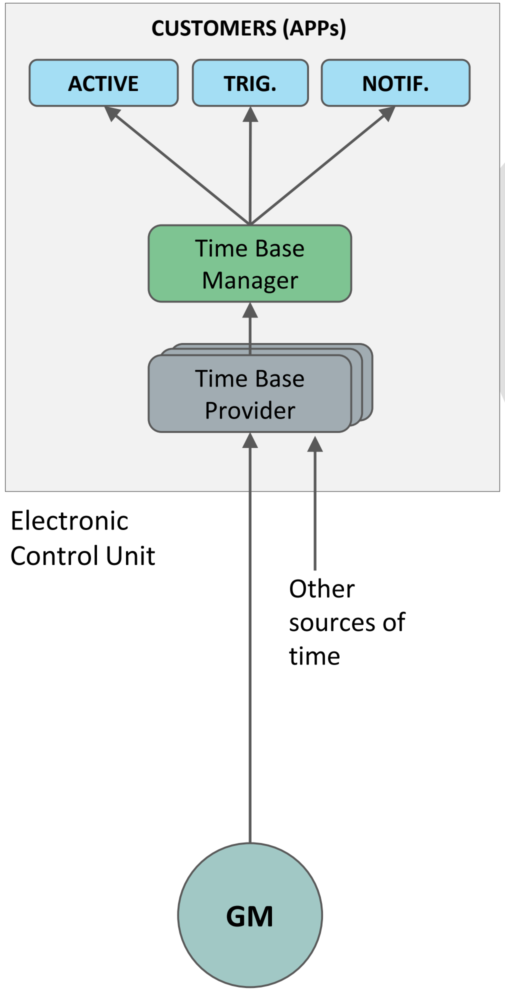
AUTOSAR – Time Sync Architecture



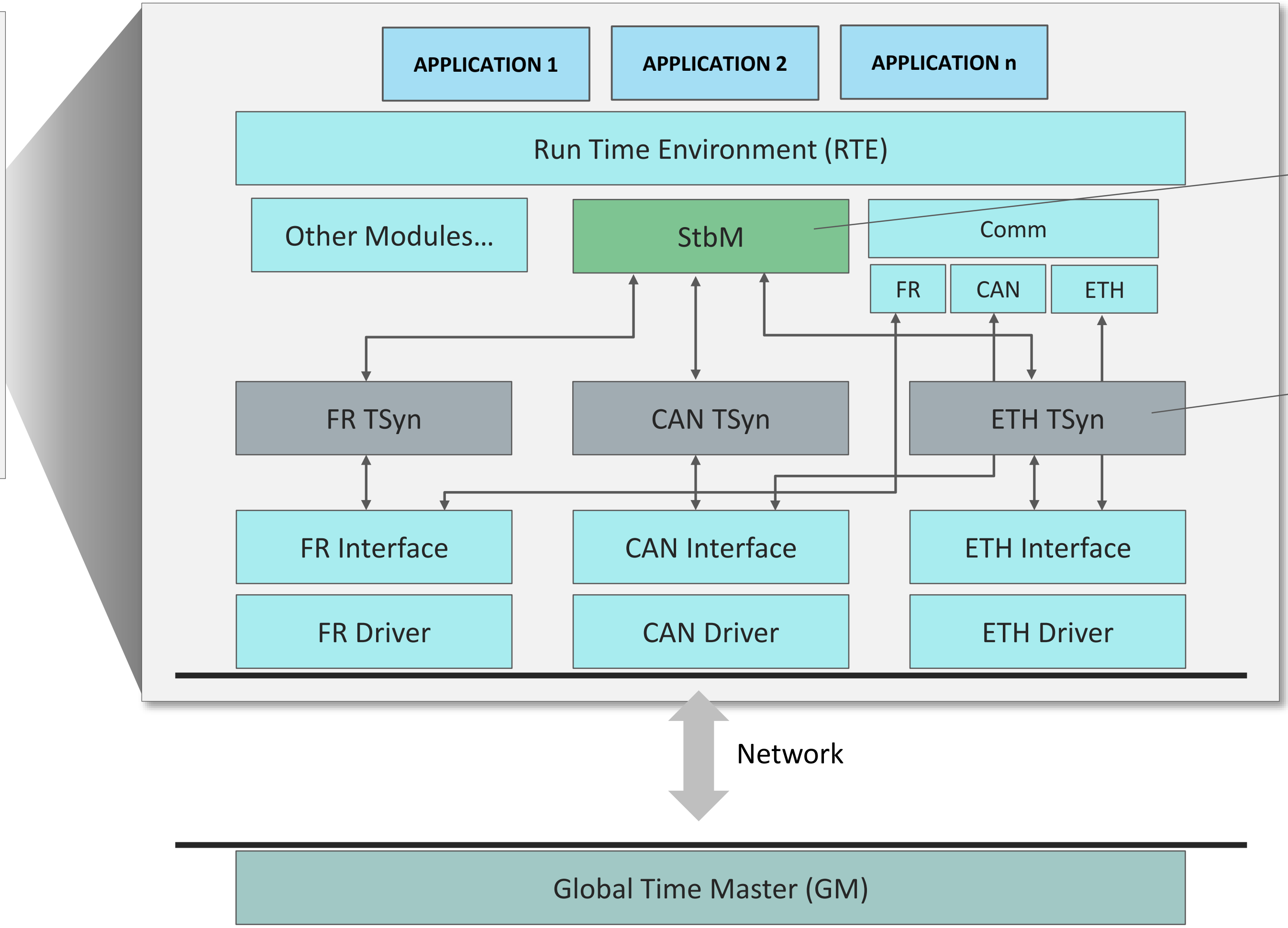
Timing for Automotive networks closely follows the time/sync architecture in telecom networks

- Global Time Master -> PTP Master
- Time Slave -> PTP Slave
- Time Gateway -> PTP Boundary Clock

AUTOSAR – Time Sync Implementation



Sync Flow



Internal Architecture

- Enables synchronized execution of Apps
- Provides accurate definition of absolute time and the passage of time

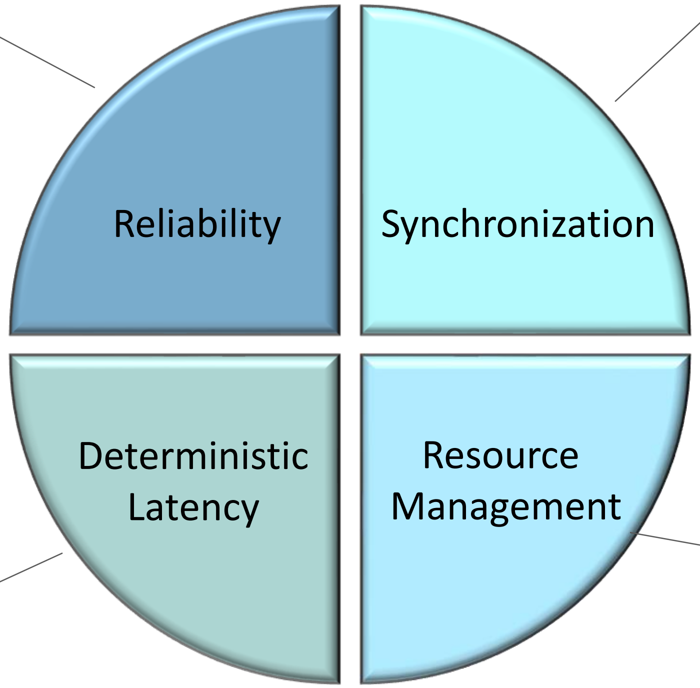
- Bus-specific Time Base Provider

TSN – Standards and Key Functionality Delivered

Key network characteristics: Bounded low latency and jitter, zero congestion loss

(P) Frame Replication & Elimination (802.1CB)
(P) Path Control (802.1Qca)
(P) Per-Stream Filtering (802.1Qci)

Timing and Sync (802.1AS-Rev) (S)
TSN Profile for in-vehicle networks (802.1DG) (T)



(P) Credit Based Shaper (802.1Qav)
(P) Preemption (802.3br & 802.1Qbu)
(P) Scheduled Traffic (802.1Qbv)
(P) Cyclic Queue/Forward (802.1Qch)
(P) Asynchronous Shaping (P802.1Qcr)

TSN configuration (P802.1Qcc) (P)
YANG (P802.1Qcp) (P)
Link-local Reservation (P802.1CS) (W)

(P) Published
(W) Working Group Recirculation
(S) Sponsor Ballot Recirculation
(T) Task Group Ballot

What Makes Automotive Different?

Characteristics/Requirements	Time/Sync Implication
NETWORK • Pre-configured, static network • Low latency network • Link segments are shorter; fewer (2-3) hops • Guaranteed end-to-end max-latency	• BMCA not required • Announce messages not required • Link delay measurement not required • Traffic shaping and queuing ensures bounded latency
ENVIRONMENT • Shorter startup time • Environment is harsher (more stringent EMC, temperature, etc.) • Higher reliability (MTBF). Repeatability and predictability is critical • ISO 26262 compliance for safety	• Robust oscillator stability • Scope for innovation!

Industry Organizations Focused on Automotive Time/Sync

avnu.org

The Avnu Alliance is a community creating an interoperable ecosystem servicing the precise timing and low latency requirements of diverse applications using open standards through certification

www.autosar.org

AUTOSAR (AUTomotive Open System ARchitecture) is a worldwide development partnership of vehicle manufacturers, suppliers, service providers and companies from the automotive electronics, semiconductor and software industry

University of New Hampshire's InterOperability Lab (UNH-IOL)

iol.unh.edu/testing/automotive

Brings 30+ years of Ethernet test experience to the Automotive Industry
Engaged with SDOs, OEMs and Vendors (Tier 1s, Silicon, Cable, T&M)

- Supporting IEEE 802.1/.3, and Alliance efforts (OPEN & Avnu)
- Active in IEEE 802.1DG (TSN Automotive Profile)

Develops Timing/TSN Test Tools, Test Plans, and 3rd party Testing services for:

- Automotive Ethernet (PHY & PCS for 100/1000Base-T1, 10Base-T1S)
- Automotive Networking (TSN Protocols (eg: .1Qbu, .1Qbv), TC8, TC11)
- Avnu Automotive Certification (including Automotive gPTP Profile)
- 1588 Testing (including IEEE Certification, 1588-2019, Security, Quality of Time)

Summary

Time/Sync is an important requirement for autonomous vehicles

Current industry implementations are very ad-hoc

Standardization work is ongoing

Lots of scope for innovation

CREDITS

Special thanks to Bob Noseworthy, UNH-IOL, for content and review

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