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An AUTOSAR Based Approach to Time Synchronize In-Vehicle ECUs in Mixed Network Architecture

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Abstract

Time-critical applications in automotive are distributed across multiple Electronic control units (ECUs) that are connected through different in-vehicle networks. The ECUs on network protocols (CAN, Ethernet, FlexRay) operating at different source clocks needs to be synchronized to achieve time sensitive functionalities. Currently CAN and Ethernet have their own synchronization mechanisms. In a mixed architecture, challenge is to synchronize nodes on different protocols connected via gateway. AUTOSAR describes concept called Time gateway for such applications. This paper describes how time gateway can be configured for synchronizing nodes on CAN and Ethernet Networks. The approach is evaluated using bench simulation configured through Vector/Elektrobit software. The outcome of the method is to measure accuracy of synchronization between two nodes.

Introduction

Modern vehicles are equipped with many time critical applications such as sensor fusion, Event data recording, sensor data readout and synchronous actuator triggering[1,2]. These applications need to run on common time base to ensure functionalities work precisely and safely[3]. Typically, time synchronized applications in vehicles are deployed in various electronic control modules that are connected to different communication networks such as CAN, Ethernet and Flexray. Each network has different protocols to synchronize timing information. Autosar[4] specifies time synchronization mechanisms for CAN[5], Ethernet[6] and Flexray[7] with worst case accuracy of 10μs, 1μs, 10μs respectively. Also, Autosar defines time gateway[8] requirements to enable global time base to be propagated into different network domains such that nodes on all vehicle networks can be synchronized to common time base.

Flexray being expensive and with the advancement of ethernet solutions in Automotive, most of modern vehicle architectures are equipped with CAN and Ethernet networks predominantly to meet vehicle's communication demands for time critical applications. This paper considers CAN and Ethernet as mixed in-vehicle network architecture and explains a design approach to time synchronize nodes in CAN and Ethernet networks[9] using Autosar time synchronization solution. Remaining of this paper is organized as follows: Section 1 briefly describes Autosar software architecture that supports time sync requirements, Section 2 and Section 3 describes concept of time synchronization over CAN and Ethernet respectively. Section 4 briefs time gateway between CAN and Ethernet networks. Sections 5 details bench setup of concept and derived results. Finally, Section 6 concludes the paper followed by references.

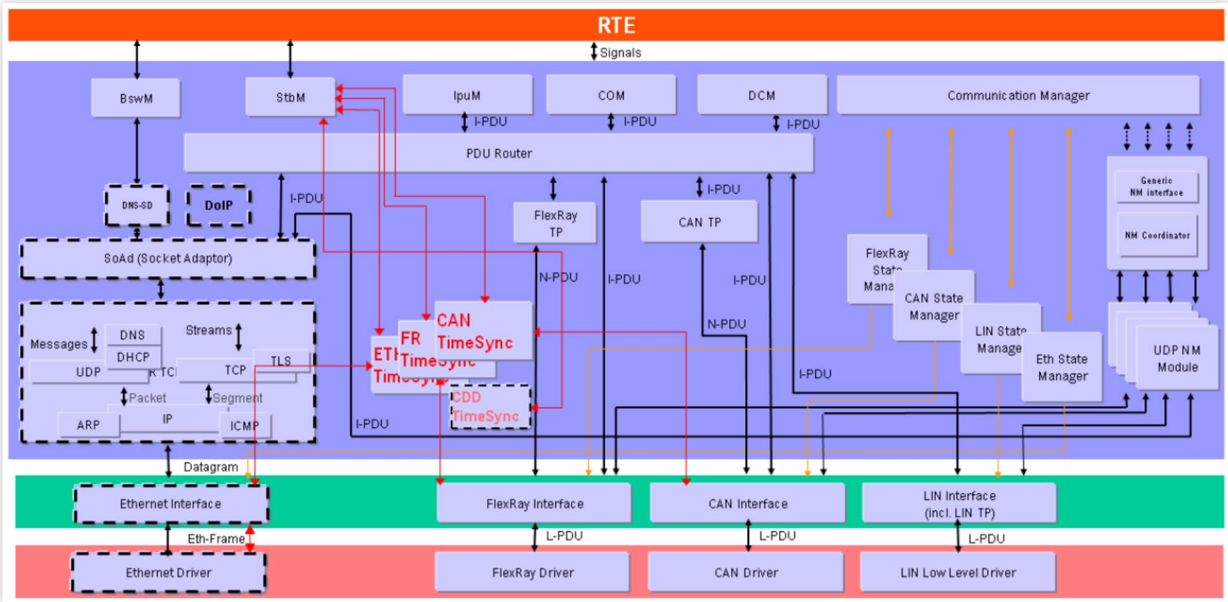
Autosar Architecture

Figure 1 details Autosar[4] Classic Software architecture with different basic software components supported as part of 4.2.2 version of Autosar release. Software requirements for time synchronization are specified in standard BSW modules: Synchronized time base manager[8], Time synchronization over CAN[5], Time synchronization over Ethernet.[6] Detailed explanation of requirements, functional specification and configuration of BSW modules are out of scope of this paper and can be referred in Autosar requirement documents.[4]

Time Synchronization over CAN

Time Synchronization in Controller Area network (CAN)[4] consists of CAN time master which provides a time base and propagate this timing information as part of synchronization messages on network. Slave Nodes will receive the timing information message for synchronizing the slave time to Master time. It is necessary to synchronize the time of all the slave nodes connected to the same Controller Area Network to the time of the Time master node so that all nodes in the network are in synchronization. There are four types of

FIGURE 1 Clustering of Time Sync modules in Autosar Software architecture[6]

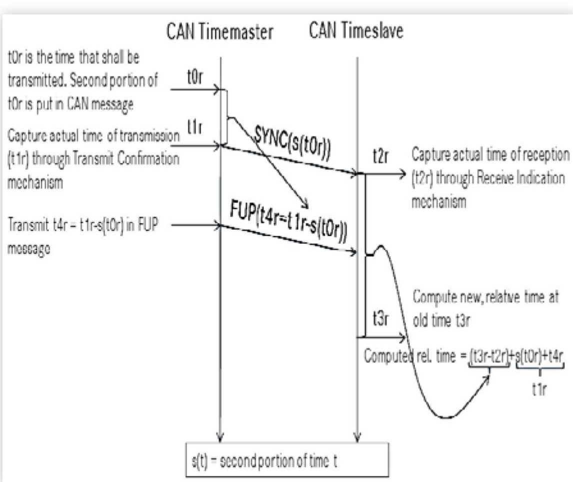


message formats which are supported in CAN for Synchronization:

1. SYNC: Time Synchronization Message
2. FUP: Time Adjustment Message
3. OFS: Offset Synchronization Message
4. OFNS: Offset Adjustment Message

As shown in below Figure 2: t0r is the relative time before transmission of CAN message from Master. CAN Time Master will start transmission of SYNC message at t1r, which contains timing information in seconds, to all the slave nodes in same CAN Network. Slave node will receive the SYNC message through receive indication mechanism at t2r time. At the End of SYNC message, CAN time Master will send FUP message at t4r which contains timing information in nanoseconds to slave nodes in the network. Slave will calculate new relative time as ((t3r-t2r) + s(t0r) +t4r) and synchronize to master accordingly.

FIGURE 2 CAN time synchronization mechanism[5]



After this master will transmit Offset messages with seconds and nanoseconds information to slave nodes periodically to ensure timing information is in sync.

Time Synchronization over Ethernet

Ethernet Time Synchronization feature is used to provide a common time base for different ECUs in a vehicle network over Ethernet. Autosar provides this feature for Ethernet[6] as defined by gPTP (generalized Precision Time Protocol) IEEE 802.1AS[10] standard. This specifies a common "application clock" between the master clock and slave clock within 1 us error under condition of

1. Full-duplex Ethernet link are 100 Mbit/s or better. (Section 5.4 of 802.1AS-2011)
2. Master clock and slave clock are separated by no more than 7 hops (Section B.3 of 802.1AS-2011)

FIGURE 3 Time Synchronization in Ethernet

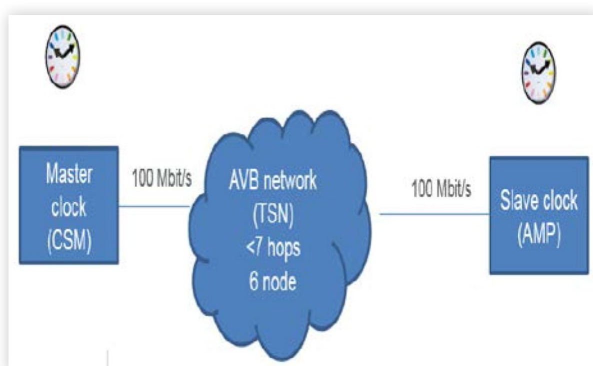
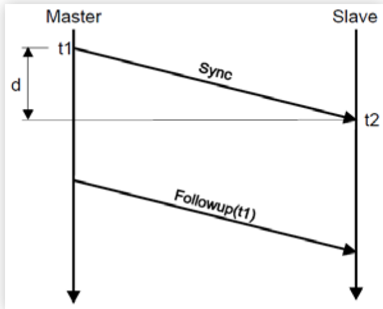


FIGURE 4 Flow of time sync messages



i.e. ABS {(time on Slave clock) - (time on Master clock)} <=1 us

Time Sync ECUs are assigned with the following roles based on the functionality:

System wide Global Time Master: A Global Time Master is the system wide origin for a given Time Base. Its Time Base values are distributed via the network to the Time Slaves. This role is assigned for 1 ECU in a vehicle Network.

Time Master: A Time Master is an entity which is the master for a certain Time Base and which propagates this Time Base to a set of Time Slaves within a certain segment of a communication network, being a source for this Time Base. There can be many Time Masters in a Vehicle Network.

Time Masters transmits Sync and FollowUp messages to the connected slaves for that time domain.

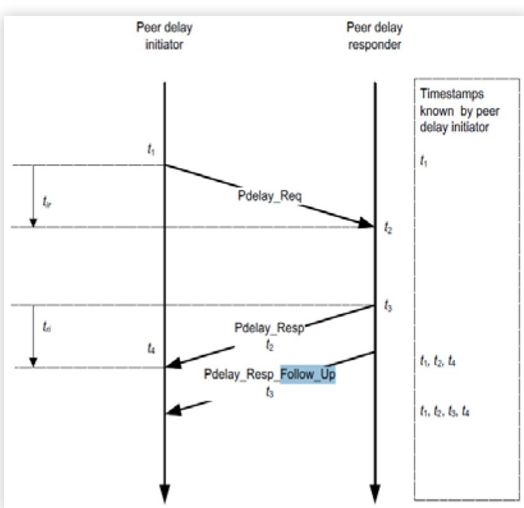
Time Slave: A Time Slave is an entity which is the recipient for a certain Time Base within a certain segment of a communication network, being a consumer for this Time Base. There can be many Time Slaves in a Vehicle Network.

The slave ECU computes the offset between the its time base and master's time base.

$$\text{Offset} = \text{t2} - \text{t1} - \text{d}$$

where d is the propagation delay which is calculated as defined below.

FIGURE 5 Time sync messages as per 802.1AS[10]



Peer delay initiator – Ethernet Slave

Peer delay responder – Ethernet Master

$$t_{ir} = t_2 - t_1$$
$$t_{ri} = t_4 - t_3$$
$$D = \frac{t_{ir} + t_{ri}}{2} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$$

Sources of Time Stamping

Hardware Time Synchronization: Some of the Ethernet controllers in the market, has an integrated clock and for these controllers this feature can be enabled. The timing information for the ingress and egress frames will be monitored by the Ethernet controller and provide to the Time synchronization module for updating in the FollowUp message.

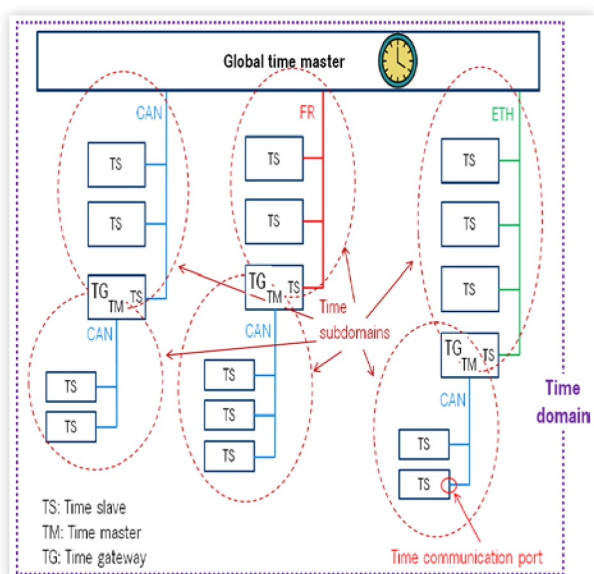
Software Time Synchronization: The free running OS counter is used for software Time stamping and accessed by the time synchronization module.

$$\text{Offset} = \text{t2} - \text{t1} - \text{d}$$
$$\text{d} -> \text{propagation delay(path delay)}$$

Time Gateway

An ECU can act as time slave in one network and time master in another network to propagate the Global time to different networks. Autosar StbM Time Gateway functionality[8] is used for this concept. The time slave receives the Time base from the System Wide Global Time Master and propagates the Global time to all the Masters (for different networks) connected to the Gateway.

FIGURE 6 Autosar Time gateway[8]



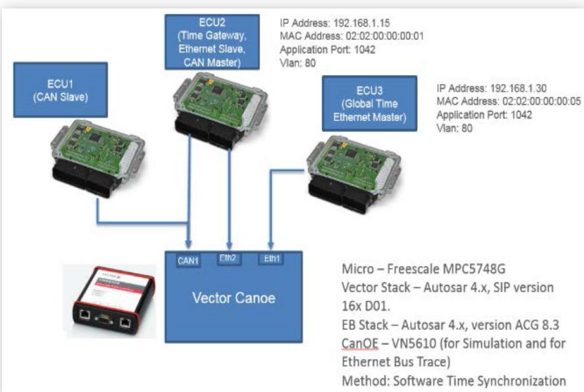
Bench Setup and Results

Figure 7 demonstrates our bench setup which consists of 3 ECUs that run on Calypso MPC5748G[11] Controller hardware and Elektrobit ACG8.3[12] Autosar Software stack version 4.2.2[4]. Network Logs are captured using Vector Canoe tool version 9.0.SP5[13]

Three ECUs under test are configured with below roles:

- ECU3 - System wide Global Time Master (Global Time base provider on Ethernet).
- ECU2 - Time Gateway (Ethernet Slave provides the synchronized time to the CAN Master using Autosar StbM)
- ECU1 - CAN Time Slave (Gets synchronized to the CAN master timing which would be same as the Global time)

FIGURE 7 Bench setup demonstrating time synchronization over CAN and Ethernet



ECU3 which is System Wide Global Time Master propagates Global Time from Ethernet Master to Ethernet Slave(ECU2). Ethernet Slave will compare its local time base with global time and Synchronize to the master time.

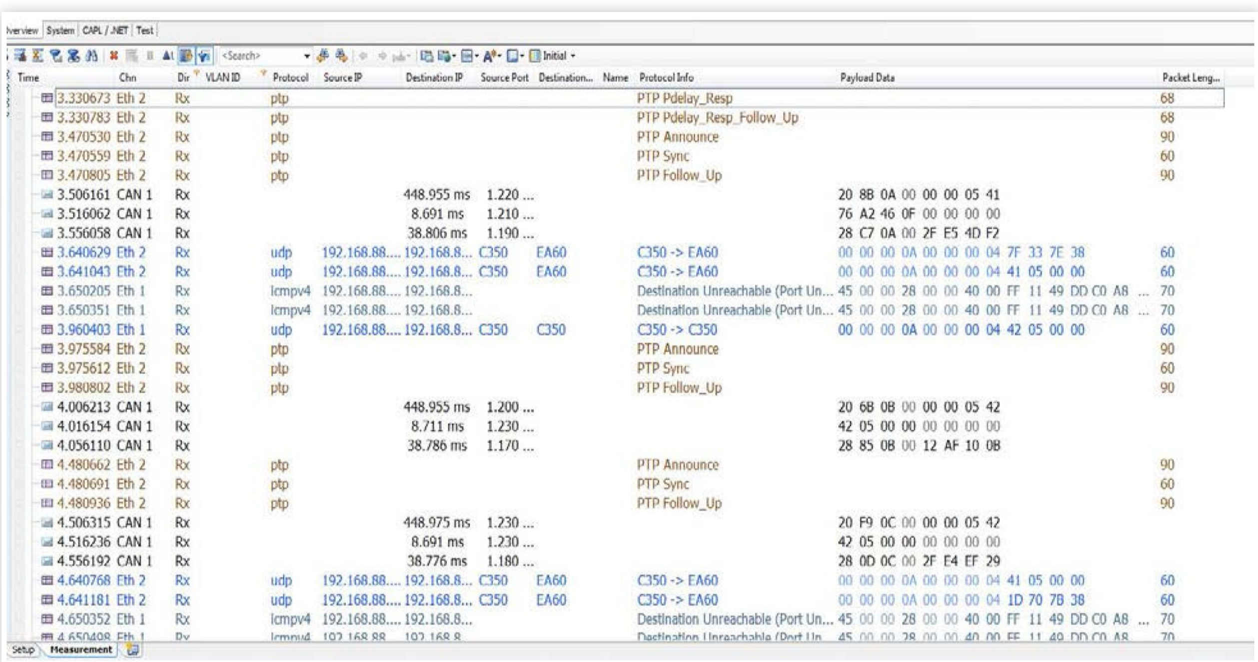
As shown in Figure 8 log, PTP delay_Req, PTP delay_Resp, PTP delay_Resp_Followup, PTP Announce, PTP Sync frames are used for Synchronization between ethernet master and ethernet slave. Synchronized time is propagated from Ethernet Slave to CAN master in time Gateway using StbM software module[8] in ECU2. CAN master ECU2 will transmit this time to CAN slave(ECU1) through Sync message (Byte0: 0x20) and FUP message (Byte0 :0x28) frames using CanId:0x118.

Also, we observed nodes on CAN and Ethernet are synchronized by worst case timing accuracy of 10μs and 1μs respectively.

Summary/Conclusions

Autosar approach of Time synchronization through time gateway proves to be effective solution to implement Time synchronization of in-vehicle ECUs in a Mixed Network Architecture. Time gateway approach can be extended to new network protocols or topologies that a vehicle electrical architecture may implements in future. We also anticipate that Autosar introduces time synchronization requirements for new network protocols that may be introduced in future[14]. Further, AVnu[15,16] is working on standardizing IEEE 802.1AS[10] for automotive applications which may bring additional improvements for implementing time synchronization mechanisms for automotive profile time critical applications.

FIGURE 8 Bench log demonstrating time sync messages



Time	Chn	Dir	VLAN ID	Protocol	Source IP	Destination IP	Source Port	Destination...	Name	Protocol Info	Payload Data	Packet Leng...
3.330673	Eth 2	Rx		ptp						PTP Pdelay_Resp		68
3.330783	Eth 2	Rx		ptp						PTP Pdelay_Resp_Follow_Up		68
3.470530	Eth 2	Rx		ptp						PTP Announce		90
3.470559	Eth 2	Rx		ptp						PTP Sync		60
3.470805	Eth 2	Rx		ptp						PTP Follow_Up		90
3.506161	CAN 1	Rx				448.955 ms	1.220 ...				20 8B 0A 00 00 00 05 41	
3.516062	CAN 1	Rx				8.691 ms	1.210 ...				76 A2 46 0F 00 00 00 00	
3.556058	CAN 1	Rx				38.806 ms	1.190 ...				28 C7 0A 00 2F E5 4D F2	
3.640629	Eth 2	Rx		udp	192.168.88....	192.168.8...	C350	EA60		C350 -> EA60	00 00 00 0A 00 00 00 04 7F 33 7E 38	60
3.641043	Eth 2	Rx		udp	192.168.88....	192.168.8...	C350	EA60		C350 -> EA60	00 00 00 0A 00 00 00 04 41 05 00 00	60
3.650205	Eth 1	Rx		icmpv4	192.168.88....	192.168.8...				Destination Unreachable (Port Un...	45 00 00 28 00 00 40 00 FF 11 49 DD C0 A8 ...	70
3.650351	Eth 1	Rx		icmpv4	192.168.88....	192.168.8...				Destination Unreachable (Port Un...	45 00 00 28 00 00 40 00 FF 11 49 DD C0 A8 ...	70
3.960403	Eth 1	Rx		udp	192.168.88....	192.168.8...	C350	C350		C350 -> C350	00 00 00 0A 00 00 00 04 42 05 00 00	60
3.975584	Eth 2	Rx		ptp						PTP Announce		90
3.975612	Eth 2	Rx		ptp						PTP Sync		60
3.980802	Eth 2	Rx		ptp						PTP Follow_Up		90
4.006213	CAN 1	Rx				448.955 ms	1.200 ...				20 6B 0B 00 00 00 05 42	
4.016154	CAN 1	Rx				8.711 ms	1.230 ...				42 05 00 00 00 00 00 00	
4.056110	CAN 1	Rx				38.786 ms	1.170 ...				28 85 0B 00 12 AF 10 0B	
4.480662	Eth 2	Rx		ptp						PTP Announce		90
4.480691	Eth 2	Rx		ptp						PTP Sync		60
4.480936	Eth 2	Rx		ptp						PTP Follow_Up		90
4.506315	CAN 1	Rx				448.975 ms	1.230 ...				20 F9 0C 00 00 00 05 42	
4.516236	CAN 1	Rx				8.691 ms	1.230 ...				42 05 00 00 00 00 00 00	
4.556192	CAN 1	Rx				38.776 ms	1.180 ...				28 0D 0C 00 2F E4 EF 29	
4.640768	Eth 2	Rx		udp	192.168.88....	192.168.8...	C350	EA60		C350 -> EA60	00 00 00 0A 00 00 00 04 41 05 00 00	60
4.641181	Eth 2	Rx		udp	192.168.88....	192.168.8...	C350	EA60		C350 -> EA60	00 00 00 0A 00 00 00 04 1D 70 7B 38	60
4.650352	Eth 1	Rx		icmpv4	192.168.88....	192.168.8...				Destination Unreachable (Port Un...	45 00 00 28 00 00 40 00 FF 11 49 DD C0 A8 ...	70

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Definitions/Abbreviations

AUTOSAR - Automotive Open System Architecture
BSW - Basic Software
CAN - Controller Area Network
ECU - Electronic Control Unit
gPTP - Generalized Precision Time Protocol
IEEE - Institute of Electrical and Electronics Engineers
OS - Operating System
StbM - Synchronized time base manager

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