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Using Ethernet Technology for In-vehicle's Network Analysis

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Abstract— **During the last years, Ethernet increasingly became the most extensively used local area networking (LAN) technology. It became also attractive for several other fields of application like industry, avionics, automotive and telecommunication. The prolonged application of this technology is principally due to its considerable assets like reduced cost, expandability and flexibility. However, Ethernet has been improved to fulfill with the specific conditions of several application fields, mainly in automotive context, is our first purpose. This paper provides firstly a general overview of Ethernet in the automotive field (especially on diagnosis process) comparing it to earliest automotive networks. Then, we will present CableFish, our optimized and high performance network analyzer. CableFish gives a real time analysis for all packets circulating between several ECUs (without loss) and allows in-car diagnosis due to the newly added HSFZ protocol.**

Keywords- Network analyzer; Diagnosis process; In-vehicle networks; Ethernet technology; Network monitoring.

I. INTRODUCTION

Networking issues have become particularly imperative in the vehicular control system's design. In the beginning of nineteen's years, a vehicle control system was put up by plain computer nodes swapping simple and fairly non-critical data. Nowadays, we have budged into distributed car control systems with several functions across many nodes from diverse vendors. Indeed, several mechanical control units have been replaced with Electronic Control Units (ECUs).

In fact, current vehicles are designed with an increasing number of ECUs (More than 70 applications picky ECUs are disposed in a premium vehicle of the top class) to give advanced tasks mainly security, distraction, performance and comfort. ECUs acquire sensory entries, process them and relay control outputs to other ECUs placed at different positions in the car. These units can be used in four parts: chassis and engine control, Safety critical systems, comfort, driving assistance systems and basis services and infotainment. Such systems give better control, more comfort and security to the driver, system's consistency, and economic efficiency. Briefly, the car, as a well integrated product with diverse twigs of technology, is tending to be more consistent and intelligent. Thus, diagnostic functions are requisite to decipher the expected problems caused by ECUs.

Series of standards for car diagnostics like ISO14230, ISO14229 and ISO15765 have been published, and ECU producers have also prepared their products to support them. A universal Car Diagnostic System is considered as a communication system with two sides: an ECU as the server side and a diagnostic tool as the client side [18].

The previously developed diagnostic tool has made it available for communicating between an ECU and a PC via Ethernet. This technology has long been a standard in several fields such as the aerospace industry (AFDX®), office communications and developed engineering.

In the automotive field, the Ethernet technology had already revealed itself in the car for diagnostic access. Further use parts have increasingly been negotiated in automotive research and improvement departments, since Ethernet's real-time behavior, ease-of-integration, flexibility and scalable bandwidth (100Mbps onwards) spoke powerfully in its favor. The usage of this technology will increasingly rise thanks to the Diagnostics over Internet Protocol (DoIP) standard that permits for impeccably interfacing the vehicle to a service centre network. The DoIP standard, specified as ISP 13400, will then foster two proceeds: the use of IP for diagnosis in one hand and the substitution of the bottleneck CAN by Ethernet for the reprogramming and diagnostics of car ECUs. This substitution is required, as the CAN technology at 500 kbps has become an obstruction today. Substituting CAN with 100 Mbps Ethernet considerably decreases the time required to reprogram an Electronic Control Unit.

The diagnosis process need specific software to record and analyzes the network traffic flowing between the various ECUs (Fig 1.). The performance of the monitoring and analysis system is so important. Indeed, to perform an accurate diagnostic in such intensive in-car communication, the network analyzer must record all transited packets without loss and provide an instantaneous analyze of the recorded data.

In this paper, a high performance network analyzer for Ethernet traffic in the automotive field, called CableFish, is intended and implemented according to the lighting necessities of the in-vehicle communication progress. Our approach aims at ameliorating the in-vehicle diagnosis process. In fact, it controls local networks (between ECUs) and provides outcomes of the network analysis. CableFish

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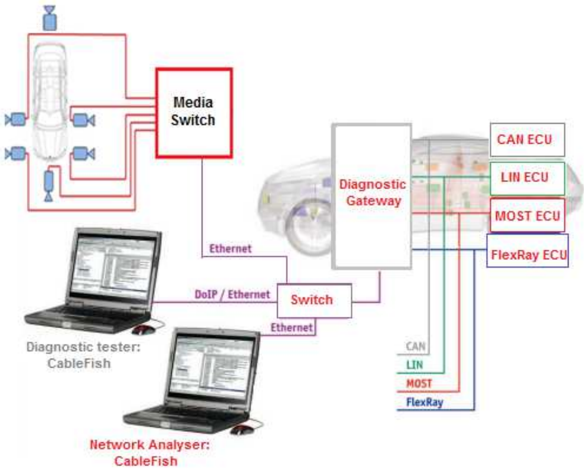

Figure 1. In-car diagnosis cycle

architecture uses a centralized (not distributed) processing solution for a customary PC: only one off-the-shelf and cost effective computer with standard characteristics. This network analyzer performs an accurate capture of the informative flow discussed among ECUs with filtering options. The filtering process can be applied in the display level also.

The main difference of the CableFish version presented in this paper and the other published ones [13][14][15] is the addition of the HSFZ and the SOME-IP decoders that allow the analysis of particular type of packets. Indeed, this new version authorizes the exploitation of CableFish for in-car diagnosis via the latest Ethernet technology.

This paper first illustrates in general the Ethernet LAN technology in the automotive field and underlines its major features. It appraises the most important automotive protocols revering each application field's conditions. Then we compare these automotive networks to Ethernet focusing on the basic concepts capabilities of each one. The second part presents the design of our network analyzer CableFish. The final part concludes the paper and outlines the errands which have to be undertaken on our research path.

II. ETHERNET IN VEHICLE NETWORK

A. *Overview of automotive networks*

The huge amounts of communication data pave the way to a raising complexity of the In-Vehicle Network (IVN), which is arranged to interconnect all ECUs and consequently higher production expends. Indeed, distributed ECUs are linked via in-vehicle networks protocols [11]. These prominent technologies include Media Oriented System Transport (MOST) [8], Local Interconnect Network (LIN) [10], FlexRay [9] and Controller Area Network (CAN) [7] and Ethernet [5], which are optimized solutions for picky use cases.

1) MOST: MOST was originally developed as a synchronous network system solution with high bandwidth for automotive infotainment. Hence, it uses the accessible bandwidth optimally for all brands of media streaming.

2) LIN: LIN consortium began in 1999 to develop a novel low cost bus for bright sensor and actuator functions, referred to Local Interconnect Network. Core members comprise BMW, DaimlerChrysler, FreeScale and Volvo. Several body control applications are often plain digital on/off operations are connected by LIN protocol, for instance activating lights, windows, wipers, climate regulator and door locking.

3) FlexRay: FlexRay was developed for a dependable real-time communication and higher bandwidth conditions (10 Mb/s). It is used for security and time-critical applications, like Dynamic Drive, and will probably continue to be used in further applications, as the power train and vehicle dynamics management domain. Presently, many researchers investigates on progressing the performance of FlexRay, e.g. developing the analysis of distributed computing systems and the optimization of Time-Triggered Systems using FlexRay technology [1].

4) CAN: CAN is a multicast common serial bus standard has been employed since the late 1980s by Robert Bosch GmbH to connect diverse ECUs originally for automotive uses as a with relatively a slow vehicle bus. This automotive protocol is applied in cost-efficient functions like driving assistance.

5) Ethernet: An upward interest to Ethernet in network vehicles' domain has been just revealed by the engineering. Several professionals for major car-creators such as BMW, and vehicular electronics corporations such as Bosch and Continental obviously attended the case to Ethernet for automotive applications [13] [6].

Briefly, Ethernet is a talented technology for in-car communications. The major benefit for this is the higher bandwidth offered by Ethernet, which exceed 100 Mbps, as compared to recent in-car networks. Such a raised bandwidth paves the way for several applications such as Advanced Driver Assistance Systems (ADASs). This application make the amount of swapped data in automotive communication incessantly grow. Besides, the use of Ethernet as a regular networking technology for in-car communications is enabled due to the assessed technology's factor. In fact, this factor appends a large knowledge that offers better maintenance, testing, and progress. The standardization and the wide use of Ethernet have put forward a large accessibility of high-quality chips and thus low-cost invention development.

B. *Ethernet vs. other automotive protocols*

By the reason to sign these protocols historic, in the first appearance of the CAN protocol, in 1991, in the Mercedes

S-Class, the protocols LIN, MOST and FlexRay became founded in the motor car. Now CAN still used in vehicular network architectures in several applications. LIN bus technology is a perfect solution for simple and cost-effective data swap of noncritical signals in the expediency region.
Where bandwidths and real-time constraints run into restrains the CAN bus system is replaced by FlexRay or MOST (where it is economically justified).
Numerous factors seem to favor the diffusion of Ethernet technology in the whole vehicular communication system. Some of them are analogous to those that encouraged the interest towards the diffusion of Ethernet in automation as a complement or substitution of usual field protocols. The automotive domain is, nevertheless, quite dissimilar to automation environments. In fact, Ethernet is a scalable technology, therefore meeting the scalability necessities inflicted by today's vehicular systems, where the amount of nodes to interconnect gradually rises.
Ethernet exploitations in vehicles are expected to increase in various areas, the main one is diagnostic. Ethernet is already applied in this domain and will sooner substitute the bottleneck CAN.
A further success step of Ethernet in the automotive field is predictable in the multimedia and infotainment application. Advanced Driver Assistance Systems connecting cameras stand for an additional use-case for Ethernet, as these functions entail high bandwidth to hold up high speed data communication and the FlexRay technology is not suitable for this.
Additionally valuable advantage for Ethernet is the support to IP. In fact, with the connectivity of Internet, the IP protocol will be applied in-car, opening the way to several applications such as navigation functionalities, smart charging in electric cars and vehicle diagnostics. Investigations into employment of the IP and the Ethernet in cars are growing in research domain, the automotive industry and corporations making automotive electronic devices (Bosch, Continental, etc.) furnishing the basis for IP as a regular networking technology intended for control units in the automotive applications.
Also BMW [5] is actually towards the exploit of Ethernet in cars. Indeed, in 2008, unshielded Ethernet was integrated as a diagnostic interface, while shielded Ethernet was integrated for Rear Seat Entertainment. BMW expect to introduce Ethernet for the Park Assist Camera intended for the new X5 in the ending of 2013. Since the gateway interrelate all protocols and ECUs in the vehicle [12], whenever a change in the application is made, the gateway has to be adapted. This may cause some evils that make an intricacy in the vehicle. To lessen the complexity of the automotive electronic architecture is the goal of many researches such as Oerman research which is synchronized by BMW. Indeed, they explore IP based communication inside the vehicle and among the vehicle and the environment. The objective is not to swap all the technologies presently in use, other than to stay using them on an IP based network and to remedy to other technologies, chosen amid those previously well established in further industrial situations, when required.
The main competitor of Ethernet are MOST and FlexRay. These networks are limited to the automotive domain, which entail a minor market dispersal and thus higher prices for products attached to these technologies. Ethernet-based in-car communication will soon start to expel MOST in its field of info- and entertainment applications [19]. Nevertheless, the full avail of a technologically incorporated in-car network will merely become rewarding with the exploitation of an Ethernet-based backbone that combine all automotive domains on an only layer at enlarged bandwidth, abridged complexity and cost, while releasing car intelligence for future novelties.
Numerous Ethernet Technologies have been examined by academic research and engineers in terms of performance and optimization. The well-known ones are Time-Triggered Ethernet [6], Ethernet/IP [17], and Ethernet AVB [16], in vehicular embarked systems.
Briefly, Ethernet is a fine solution to have upper bandwidth for future car applications at low costs, through a confirmed and broadly employed technology that has been tested in further domains (for instance avionics and telecommunications).

III. THE NEED OF NETWORK ANALYSER

To be sure of the good progress of in-car communication, particularly after adding Ethernet in numerous automotive applications, diagnosing the in-car network is mandatory. The Diagnostic systems give information about the status of the car. At first, this was driven by lawful necessities that mandated monitoring of emanation related components, but it is an imperative factor in raising the supposed quality of the system too.
As the quantity of sensors enhance, so does the requirement for diagnostics. There is a desire to enlarge the aptitude of the on-board system too; for example to detect the necessity for preventive maintenance. Thus, the customer never tries critical problems, and consequently gets an insight of high quality.

The diagnostic system comprises an in-car part and dedicated software to provide accurate analysis for the in-car information. In fact, testing the network by specific software that captures and analyses all the traffic is well required in such complex, high-volume, and high-speed network traffic. But it lies further than the precincts of most existent monitoring systems. In fact, due to the progress of current vehicular communication technologies, flexibility, scalability and real time are also necessary in network traffic analyzers.

After studying the OEMs' (Original Equipment Manufacturers) needs and the previous works incapacities, we have designed an efficient monitoring and analyzing architecture, named CableFish, which obtains the outputs of the gateway and the media switch through a simple Ethernet wire (Fig 1.). The performance of a network analyzer must satisfy the requirements imposed by the new technology,

The gateway generates a rate of 20Mb/s, while the media switch generates the sum of rates created by the interconnected cameras (in BMW modern cars, eight cameras are connected to the media switch). Every camera generates from 45 to 47 Mb/s. So, our objective is to support a rate of 400 Mb/s (20Mb/s + (47Mb/s × 8)).

To prove the performance and the efficiency of our system, we have compared it to WireShark analyzer [2] in the last part of this section.

A. The protocols supported by CableFish

- UDP: (User Datagram Protocol, RFC 768), the main advantages of this protocol are the efficiency, capability of package broadcasts and multicasting and the low-overhead communication, although, it allow sending and receiving of short data packets and do not recover the lost date.
- TCP: (Transmission Control Protocol, RFC 793), the major advantage of this protocol is the correct data transmission guaranteed by data security layer.
- IPv4 (Internet Protocol V4, RFC 791, RFC 894, etc.), it supports many network interfaces and reassembly IP fragments. This IP version has the advantage of IP Multicasting.
- IP v6 (Internet Protocol V6, RFC 2460) IPv6 was developed by the Internet Engineering Task Force (IETF) to deal with the long-anticipated problem of IPv4 address exhaustion.
- ARP (Address Resolution Protocol, RFC 826) is a telecommunications protocol exploited for decree of network layer addresses keen on link layer addresses, which is the critical assignment in multiple-access networks.
- ICMP (Internet Control Message Protocol, RFC 792) is used by the OSs of networked computers to propel error messages. It can also be employed to relay query messages. ICMP is dissimilar to transport protocols such as TCP and UDP.
- IEEE 1722 is a transport protocol realized in hardware. It is used in an Audio Video Bridging (AVB) network for packetization, session management, media format definition. IEEE 1722 allow isochronous data transmission devoid of IP and layer 4 transport protocols.
- SOME-IP [21] is the acronym of Scalable service Oriented middlewarE over IP. SOME-IP is a new protocol set by BMW research group. In fact, it is an automotive/embarked RPC mechanism. The basic feature set of the SOME/IP will be supported starting with the AUTOSAR 4.0.3. system. This permits it to parse the RPC PDUs and ship the signals to the application. However, this critical feature is not sufficient for more complicated use cases like Infotainment applications.
- HSFZ (LH 10000759), is a protocol for diagnosis of BMW. It was primary introduced in November 2008, in the 5th generation of the BMW 7-series. This important protocol is introduced in our monitoring system to allow diagnosis of BMW vehicles. This contribution gives more worth to CableFish.

B. Ethernet frame managements

While capturing on the Ethernet link, one examines all these data units; called frames, excluding the preamble and the checksum eliminated by the network card.

1) Packet capture: In our architecture, the packet capture process is accomplished by the Winpcap. It is developed for capturing link layer network packets.

The packet capture process is done according to successive steps. Firstly, it selects a network interface with the function pcap_findalldevs to find the whole network devices then use the pcap_open_live to open the particular interface. The loaded packets can be filtered by several criteria using specific data filters tool of winpcap.

The logged packets can be filtered by numerous criteria using specific data filters tool of the winpcap library, which is the most widely used by network analyzers for capturing link layer network packets.

The next capturing step is the flow generation. In this stage, the Winpcap preserve the packet header information, which are:

-- Timestamp

-- Packet length (off wire).

-- Length of portion present in the capture.

Saving packets into pcap file is the last step of the packet capture module. The dumping method of logged data is a cornerstone of the monitoring process. The increased number of distributed computing systems in the vehicle generates a tremendous amount of data and consequently requires an efficient method that guarantees the lossless and the real time requirements. Although, Winpcap technology goes far beyond accomplishing the dumping task efficiently and correspondingly to these requirements. Indeed, the Winpcap loading thread is processed by packet (one by one). For this reason, we have opted to another optimized method in terms of saving time and canceling packets loss.

To guarantee the capture of all packets without loss on the one hand, we added an extra buffer of the type FIFO in the memory. It is an intermediary between the Winpcap buffer-queue and the pcapfile. The size of this memory container was fixed 200 MB after many studies. This application buffer enhances our system's competence by guaranteeing a shrink number of system calls, i.e. reduced processor usage. This process guarantees a shrink number of

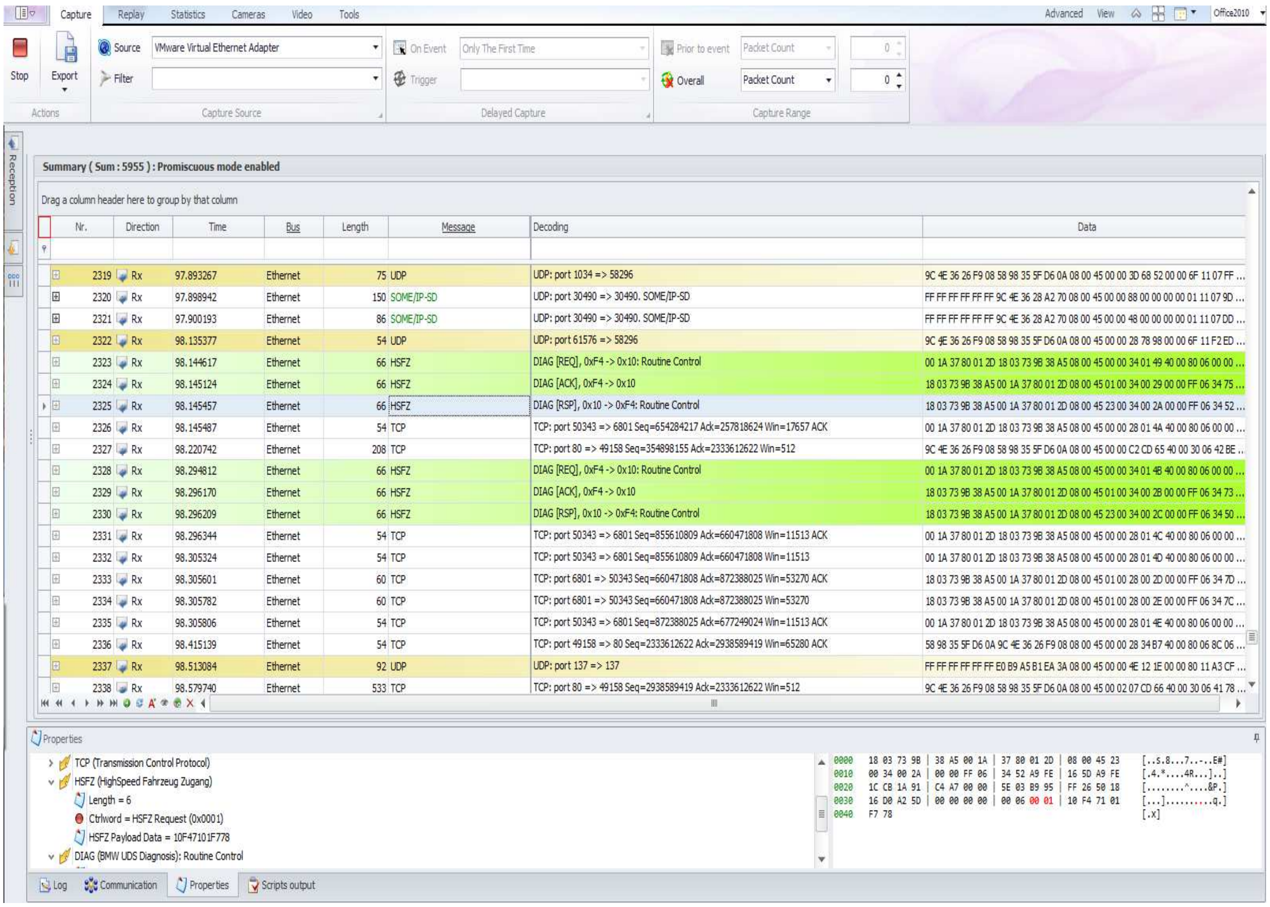

Figure 2. A screen shot of CableFish interface

system calls and consequently allows gaining a great deal of time which dishes up the real time requirement.

Furthermore, to guarantee the full network packets capture, Winpcap library proceeds in the promiscuous mode. It permits the snoop of all packets traversing the network interface, while in the standard mode, the objects working as a network interface stop packets not belonging to the host. The most imperative operation of the winpcap is to capture all packets without loss.

2) Data reader and Inedexer: The ranking of captured packets is put in an offset vector. In fact, it contains the positions of every packet in the file.

So, the total number of packets constitutes the length of the offset vector. In the online mode, the offset vector is established in parallel with the dumping process. In the offline mode, the offset vector is created simultaneously with opening the pcap file. The offset generation is done concurrently with the sequential reading of the pcap file.

After reading the packet and generating its offset, it will be stored in a little cache, which is made for the reader module. Then, we perform a plain protocol decoding for each packet and we classify them accordingly to the specified criteria (protocol name, IP address, Mac address, port number, etc.) to obtain a well indexed table. This method allows two main advantages. On the one hand, it permits pointing straight in the needed packet without passing by all previous ones. On the other hand, it allows filtering the information displayed into the packet-listing window in accordance with selected criteria concerning the protocol name or other information.

Figure 2 demonstrates a screen shot of the CableFish main interface showing the capture of HSFZ and SOME/IP packets.

IV. Comparing CableFish to WireShark

In this subsection we present an evaluation of our CableFish system in terms of performance and resource efficiency by comparing it to WireShark system.

Most of the monitoring systems suffer noticeable losses if the network is overloaded by the huge number of packets per second. Certain packets are lost in the kernel level for two reasons. Either due to the lack of CPU time, if a new packet comes when the tap has been processing the preceding one or, the kernel buffer is full and it has no more space to amass the incoming packets. Other packets can be lost in the user level for almost the same reasons: high CPU exploitation and limited buffer's capacity.

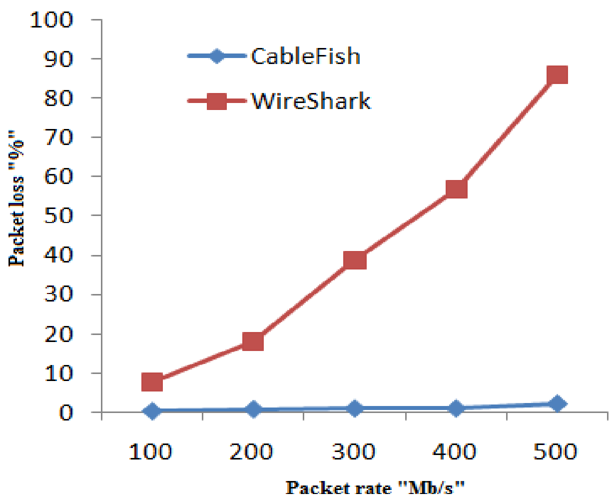

Figure 3. Packet loss for different packet rates

Figure 3 illustrates the average percentage of lost packets while replaying the trace through speeds ranging from 100 to 500 Mbits/s. As shown in the curve, CableFish has the least rate of packet loss even in high packet rates.

V. CONCLUSION AND PERSPECTIVES

In this paper, we have presented a general overview of the introduction of Ethernet technology LAN in the automotive field grace to its various advantages, including real-time behavior, ease-of-integration, flexibility and scalable bandwidth (100Mbps onwards). Then we have described our Ethernet traffic monitoring and analyzing system, CableFish, which allows, firstly, capturing voluminous informative flow circulating in-vehicle network, without any loss; Secondly, opening a huge file in real time, and providing an exact analysis result. So, it can be a source of accurate information for many applications like automotive diagnosis. The new of CableFish is its adaptation with the latest needs of performing diagnoses using Ethernet. Indeed, CableFish is now able to make an accurate diagnose grace to the addition of HSFZ and SOME-IP protocols.

Although basic features and processes were implemented for CableFish, improvement remains vast in undiscovered domains. We anticipate applying simulations for real ECUs.

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REFERENCES

[1] H. Zeng, M. Di Natale, A. Ghosal, and A. Sangiovanni-Vincentelli, “Schedule Optimization of Time-Triggered Systems Communicating Over the FlexRay Static Segment,” *IEEE Trans Ind. Informat.,* Vol. 7, No. 1, pp.1 – 17, Feb 2011.

[2] U. Banerjee, A. Vashishtha, M. Saxena, “Evaluation of the Capabilities of WireShark as a tool for Intrusion detection *Journal of Computer Applications*, pp. 1 – 5, Sep. 2010.

[3] P. Dimitar, Filev, R. Babu, F. Tseng, and P. Baruah,“An Industrial Strength Novelty Detection Framework for Autonomous Equipment Monitoring and Diagnostics,” *IEEE Trans Ind. Informat.,* Vol.6, No.4, pp.767 – 779, Nov.2010.

[4] B. Wolfgang, “MOST in driver assistance,” *The special issue for the 4th MOST Forum*. Mar. 2012.

[5] R. Bruckmeier, “Ethernet for automotive applications,”*In freescale Technology Forum, Orlando,* [online] available: http://www.freescale.com/les/ftf 2010/Americas/WBNR FTF10 AUT F0558.pdf. *2010.*

[6] T. Steinbach, F. Korf , and T. C. Schmidt, “Comparing Time-Triggered Ethernet with FlexRay:An Evaluation of Competing Approaches to Real-time for In-Vehicle Networks,” *IEEE Proc. WFCS*, pp. 199 – 202, May. 2010.

[7] Road Vehicles—Interchange of Digital Information—Controller Area Network for High-Speed Communication, ISO 11 898, 1994. 7

[8] MOST Cooperation. (2004, Aug.) MOST Specification Revision 2.3. [Online]. Available: http://www.mostnet.de

[9] FlexRay Consortium., FlexRay Communication System, Protocol Specification, Version 20. [Online]. Available: http://www.flexray.com , *Jun. 2004.*

[10] LIN Consortium. (2003, Sep.) LIN Specification Package, Revision 2.0. [Online]. Available: http://www.lin~subbus.org/

[11] K. Seongwoo, L. Eundong, C. Mideum, J. Hanyou, S. Seungwoo,“ Design optimization of vehicule control networks;” *IEEE Trans. Veh. Technol.*, Vol.60, No.7, pp. 3002 – 3016, *Sept.2011.*

[12] H Zinner, J. Noebauer, T. Oallner, J. Seitz, and T. Waas, “Application and realization of gateways between conventional automotive and IP/Ethernet based networks”. *In Proc. ACM/EDAC/IEEE). DAC'11*, pp 1 – 6, Jun. 2011.

[13] H. Lajmi and A.M. Alimi, “Optimized packet processing architecture for Ethernet trafic Monitoring and Analysis in the Automotive Field,” *International Journal of Vehicle Information and Communication Systems (IJVICS),* 2013*, in press.*

[14] H. Lajmi and A.M. Alimi, “PEMONAS: Passive Ethernet traffic MONitoring and AnalySis system”, Proc. *IEEE ICCIT,* June 2012, pp. 161 – 165.

[15] H. Lajmi and A.M. Alimi, “HP-EMAA: High Performance Ethernet Traffic Monitoring and Analysis System in the Automotive Field,” Proc. *IEEE CICSyN*, July.2011, pp. 348 – 351.

[16] A. Kern, H. Zinner, N. Streichert, J. Noebauer, and J. Teich, “Accuracyofethernet AVB time synchronization under varying temperature conditions for automotive networks,” *ACM/EDAC/IEEE Proc. DAC,* pp. 597-602, Jun. 2011.

[17] A. Kern, H. Zhang, and J. Teich, “Testingswitched Ethernet networks in automotive embedded systems,” *IEEE Proc. SIES*, pp. 150 - 155, Jun. 2011.

[18] Y. Zheng, L. Feifei, L. Feng, “Vehicle Remote Diagnostic System Implementation Based on 3G Communication and Browser/Server Structure,” *International Conference on Information Engineering, Lecture Notes in Information Technology*, Vol.25, pp. 160 – 166, 2012.

[19] J. Noebauer, H. Zinner, “Payload efficiency and network considerations of MOST and Ethernet,” *Elektronik automotive. Special issue MOST.* Mar. 2011, pp. 14-17.