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Comparison of Automotive Protocols for the Diagnostic Purpose

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Abstract:- This document is regarding the selection of a well suited protocol for the diagnostic purpose in the automotive industry. Various protocols are compared with respect to their parameters like speed, bandwidth, weight and cost effectiveness. Time critical activities require speed for the communication purposes and also for upgrading or reprogramming the ECU. Selecting a perfect protocol for the diagnostic purposes assist in the proper functioning of the vehicle which in turns increases the safety of the occupants.

Keywords:- *Diagnostic protocol; Automotive communication bus; OBD; UDS;LIN; CAN and Ethernet.*

I. INTRODUCTION

Modern automotive system consists of more than 150 ECU's keeping track of various tasks in the vehicle. Each ECU in the vehicle has its own specific function to perform. The ECU gets input from the sensor and actuator that are placed inside the vehicle. The ECU also gives the output signal to actuate the change if the system or the subsystem doesn't work properly. In order to reduce the complexity of wiring in the automotive industry, SAE has come with some standard protocols for effective communication in the bus. The function of this bus is to ensure proper delivery of message with minimum delivery time and it should be cost effective also. Some of the bus communication protocols includes CAN (Controller Area Network), LIN (Local Area Network), Flex Ray and Ethernet.

Whenever there is an improper function in the vehicle which in turns gives signal to the ECU, a DTC (Diagnostic Trouble code) is generated. The generated DTC's are stored in the EEPROM for the later references. Fixing the DTC's in the ECU are done by the professionals in the automobile diagnostic center. The DTC's are then electrically erased from the memory. These are generated again as soon as the vehicle starts if not fixed properly in the first attempt.

The diagnostic tool reads the data in the form of the DTC's from the EEPROM to fix the error in the ECU. The DTC's indicates the exact location of the error or the fault which save the time and prevents the introduction of other error in the working systems. The DTC codes located in the memory of the ECU is modified by the tester.

Diagnostic is a the process of identifying the problem in a system and then rectifying it so that the system starts to work the way it was meant to be. Any system which don't give the intended output is said to be broken or in faulty state. The diagnostic is done in order to retain its original working to get the required output. Similarly, in automotive system, diagnostic helps to solve the improper functioning of the system by resetting the system or by upgrading it. Automotive diagnostic tool is the way of repairing fault in the given vehicle.

II. LITERATURE SURVEY

A. CAN(Controller Area Network)

The Controller Area Network, usually referred to as CAN, is a serial communication decorum that was primarily industrialized for automotive use. It was created to exchange data among the nodes. It was established by Robert Bosch in 1983.

It was released formally by the Society of Automotive Engineering (SAE) in 1986, as a standard CAN. In terms of speed, transfer data can take place in a range from 125Kbps to 1Mbps. It is a double wire protocol having CAN high and CAN low (CAN L and CAN H). The key purpose of developing CAN was to attain quicker communication amid the nodes and to diminish Electromagnet Interference (EMI) due to the wiring cables in the vehicle. The properties of this protocol like rapid response and fault tolerance made it prevalent in aerospace, automotive and manufacturing industries.

It is a message based protocol and nodes get the bus based on arbitration. Here, the priority of the nodes is assigned depending on the arbitration. A higher priority node is allowed first get access of the bus and the node with lower priority waits till the transmission completes. Once the bus is free, the lower priority message gets into the action. Due to this reason the higher priority messages are delivered but the lower priority message fail to meet the deadline[1].

It is a multi-master bus communication which communicates information over the network based on the OSI and ISO layer model. As defined in the ISO 11898, this protocol make use of the physical layer, the transfer layer, the object layer and the application layer. The protocol layers are shown in the Fig.1.

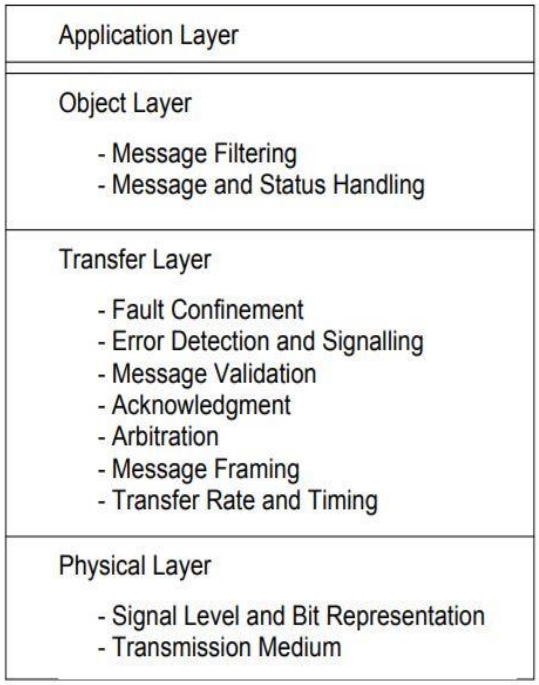

Fig.1:- CAN Protocol Layer

There are two types of frame formats listed below:
1. Standard CAN
2. Extended CAN.

The standard CAN frame format, as shown in The Fig.2, is an eleven bit identifier. The extended CAN has eighteen bit identifier. The frame format of CAN consists of Start of Frame (SOF), Remote Transmission (RTR), Data length code (DLC), Cyclic Redundancy Check (CRC) and End of Frame (EOF).

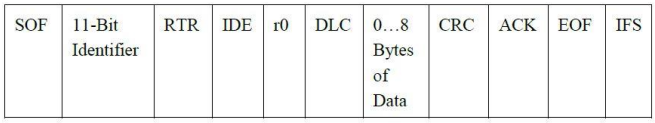

Fig. 2:- Standard CAN Frame Format

The CAN Bus uses logic high as zero and it is known as the dominant bit. Then logic low is one and it is known as the recessive bit. Due to this reason, the transmitter's input and receiver's output are internally pulled up. Usually, CAN deals with the smaller frames with extreme payload of eight bytes that is to be communicated over the whole network that may causes data consistency among the network.

B. LIN(Local Interconnect Network)

The response speed and cost of deploying it in the vehicles plays a main part in choosing the network technology. When the dealing is with the mechanical components which require low speed processes, LIN protocols is used. It is used to control actuators and to read data from the sensors. Because of its low computational power, less amount of memory and low cost oscillators, it is fit to control the body domain in automotive industries. LIN is a master-slave mechanism and the data rate can't be higher than 20Kbps due to EMI limitations. The Fig.3 below, shows the LIN frame format in the bus communication system.

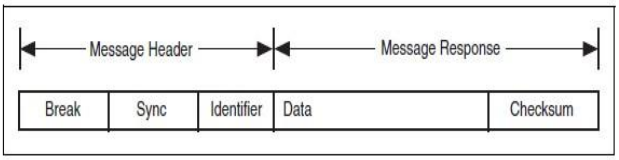

Fig. 3:- LIN Frame Format

LIN is a time-triggered network and the LIN master performs the role of bus arbiter with the help of Master Task and LIN Schedule table. The LIN frame contains six bit address identifier and two bit check field to identify node in the network[2]. LIN master contains the predefined scheduling tables which have different relative timing regarding when the data should start sending. LIN master contains the special message called tokens on the bus along with a specified time point. The token is referred to as a request and it contains the message address. It is checked by the LIN slave and the salve has three alternative message to react back to the token. The three alternative message are:

1. Send data
2. Receive data and
3. Ignore data.

Both token and data are considered as the LIN messages. If there is no request for the bus, there will no response from the slave side, which leads to save the bandwidth. LIN protocols are used in some basic low speed and non-critical applications in vehicle which include sunroof, seat adjustment , doors and windows, where the speed and accuracy is not a main factor.

The LIN 2.0 specification is further divided into following frames:
1. Unconditional LIN frame.
2. Event triggered LIN frame…
3. Sporadic LIN frame.
4. Diagnostic LIN frame.
5. Network management frames[3].

C. ETHERNET

One of the efficient protocols used in the automotive is the Ethernet protocol. It is a wired communication protocol intended especially for the office environment purpose. The physical layer of this protocol is unshielded twisted pair cable (USDT). Due to its EMC/ EMI problems, it was unfit for the other applications in the earlier days. But now a days, by using advanced techniques, the above mentioned problem can be avoided. Usually network traffic , flow control occurs in the office environment because of large amount of data transferring. The same is due to more number of users in the same network. Ethernet is well suited to encounter the problems now. This also makes it suitable carrier of messages for the

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automotive industry, as more number of nodes and large amount of data are used in the vehicle[4].

Originally the Ethernet was designed for a larger bandwidth. Later, the cost of hardware installing and jitter which makes unfit for the real- time application[5]. Due to its large scale production the cost of making hardware gradually decreased which is needed for the automotive manufacturers[6].

The number of ECU's in the vehicle are more. Each ECU has different function to perform and handle certain subsystems. The communication between the different ECU's and between the sensors and the ECU takes place by some protocols like CAN, LIN and Flex-ray etc. Some models of BMW make use of the Ethernet protocol because of its low cost and higher bandwidth. The Fig.4 below shows the frame format of Ethernet.

Fig. 4:- Ethernet Frame Format

Frame format of Ethernet includes following:
1. Destination address
2. Sources address
3. Data length code payload or data
4. Padding
5. Cyclic Redundancy Check (CRC).

The payload of Ethernet frame ranges from 0 bytes to 1500 bytes. Cyclic Redundancy Check is used to get acknowledgement from the receiver. By deploying additional methods in the frame format, it is made suitable for both real and non-real time applications. It can communicate in full duplex mode which prevents any traffic[7].

D. OBD

OBD is a Diagnostic protocol used on the application layer of OSI & ISO model. OBD stands for "**On-Board Diagnostic**". The ODB was first developed by Volkswagen in the year 1968. The purpose of developing OBD was to reduce the emission by monitoring the performance of the engine. The engine is manufactured to perform at various different parameters which includes speed, torque, engine rpm etc. The air fuel ratio needs to be such that maximum efficiency is attained at all speeds and at all terrain conditions with different torques. There are three stages in the air/fuel mixture defined with respect to the amount of the fuel in it as listed below :

1. Lean mixture
2. Rich mixture
3. Stoichiometric mixture

The correct amount of air- fuel ratio gives less amount of emission .The stoichiometric ratio of air- fuel is 14.7:1. The lean mixture will contain less fuel which creates hydrocarbons and dioxides of nitrogen and Sulphur which are released in the atmosphere causing pollution. If air is not properly supplied, the formation of hydrocarbons is more. Similarly, the rich mixture will create the oxides of Nitrogen, Sulphur and Carbon which are released into the air. This also cause the engine to perform under inefficient condition. In both the cases, the emissions are produced. Sometimes, knocking is also encountered while driving in such cases.

The engine ECU monitors the A/F mixture to provide the stoichiometric mixture. If the ratio is not proper, the ECU sends a signal to send the mapped or predefined Air-Fuel mixture into the combustion chamber. This reduces the emissions from the engine and also increase the efficiency.

OBD is divided into two types as follows:
1. OBD-I- The OBD-I is the first generation diagnostic protocol developed for the emission control in the vehicle.
2. OBD-II- It was developed as a updated version of above-mentioned type and was used for both emission system and the non-emission system including software update for the ECU.

E. UDS

It is a Unified Diagnostic Service used in the automotive industry to detect any error or fault in the working of the systems, subsystems, ECU's and sensors. It is called unified as it can work on all the bus types, might it be on the Ethernet or over CAN. It is an application software that can be used for various applications such as diagnostic and reprogramming the ECU in the system.

The UDS is mainly developed for the diagnostic services. There are six types of function handled by the diagnostic services for the proper functioning of the ECU . They are

1. Diagnostic management
2. Input and output controls
3. Memory management
4. Data transmission
5. Upload/download control unit
6. Upload/download polling unit.

The diagnostic management takes care of the generation of DTC's , if there is any improper functioning of ECU. The purpose of data transmission is to check whether the data has been transmitted properly and completely. The input and output unit controls the Input/output pins of the ECU[8]. The ECU gets inputs from the sensor and sends actuates the actuator of the system. For the proper functioning of the system the sensors should be calibrated periodically. The memory management has to manage the storage of DTC's in the EEPROM for later reference.

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Every action in the node is monitored by the ECU, which makes it a kind of black box device in the car. The user can't access the ECU without proper diagnostic tools. Once the installation of all the ECU's in the car is completed and the tester needs to test the functioning of the car, the only way is to communicate with the bus and the application layer running on the chip. The input and output pins of the ECU can be tested easily by the technician if the UDS application is present in the vehicle. It is an international standard protocol so that error management can be done by the tester easily.

III.METHODS & IMPLEMENTATION

There are different methods that can be used for diagnostic purpose. Each protocol has its own requirements and standards. Each protocols have their different response time, ease of implementation, better bandwidth and hardware requirements.

This paper will discuss about commonly used methods for the diagnostic services.

A. OBD Over CAN

The OBD protocol uses CAN as the communication bus. The maximum data rate is up to 1Mbps . The response time and bandwidth are better, compared to the other protocols. The number of the automotive systems, subsystems, sensors, actuators and ECU's in the vehicle are increasing with rise in technology. The ECU's gets the input from the oxygen sensor, throttle sensor, coolant sensor, MAP sensor and temperature sensor . By controlling and monitoring the sensors, the emission of vehicle can be reduced and fuel efficiency can be increased.

OBD comes with some standards, so that the technician can easily understand the internal error of the vehicle easily. When any error or any malfunctioning in any part of the vehicle happens, the Diagnostic Trouble Codes (DTC) will be generated.

The DTC's will specify the exact location of the error and will save time of the technician in searching the fault location. The DTC's are stored in the EEPROM of the controller for the lateral retrial. This can be erased electronically whenever required.

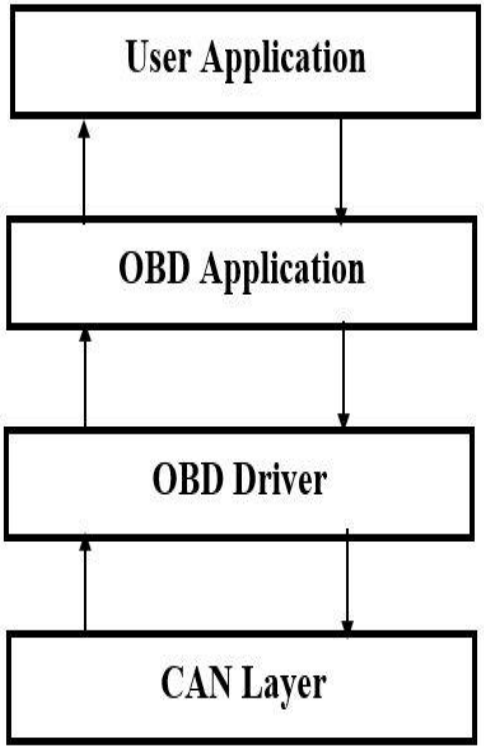

Fig. 5:- OBD Over CAN

To provide the customer, a more safer and a comfortable ride, updating of the vehicle is done. This is increasing the complexity of the vehicle and the automotive has become more prone to errors. The Fig.5, illustrates the architecture level of OBD over CAN.

The increasing number of systems are gradually giving rise to the number of errors which in turn are giving rise in the DTC .When more number of DTC get into the show ,the bandwidth becomes the issue. The bandwidth of the CAN is lesser as compared to the Ethernet protocol.

B. UDS Over CAN

UDS stands for Unified Diagnostic Protocol .The word unified means that it is the standard diagnostic protocol that can communicate over CAN, LIN, Flex ray and Ethernet. The diagnostic service is placed in the application layer and the communication service is placed from one to six layers of the OSI and ISO model.

The communication between the ECU follows two methods , namely, Physical and Functional addressing. In physical addressing, point to point ECU can be accessed, whereas, in the functional addressing, the tester can communicate with multiple ECU's in the network. The Fig.6, shows the architecture level with reference to the OSI & ISO model.

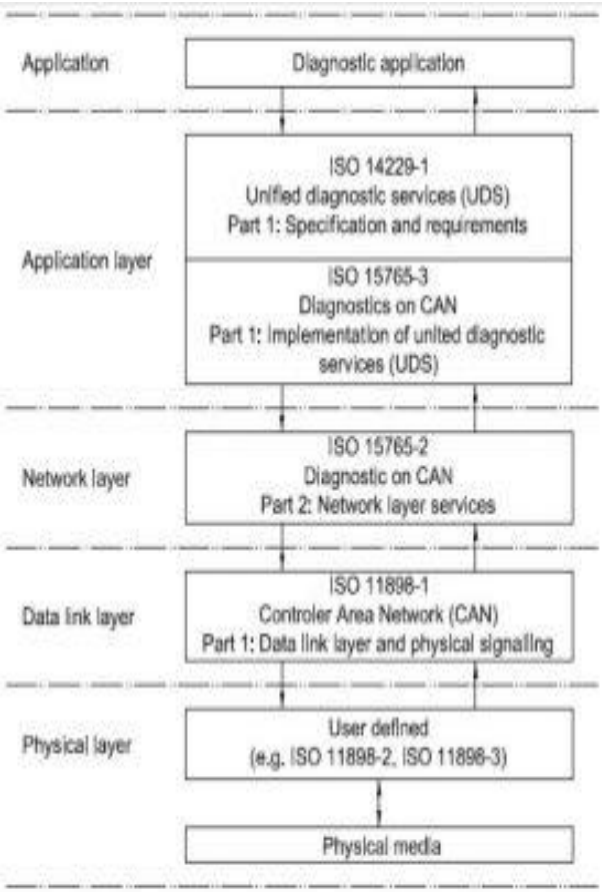

Fig. 6:- UDS Over CAN

The main purpose of developing this protocols is to check that whether each ECU in the vehicle is functioning properly without fault in the system. The diagnostic consists of two session, a tester (Client) and the ECU (Server). Diagnostic service request start from the client to sever. Once the client is requests, the server may send acknowledgement in three types classified into positive, negative or no message from the ECU.

This protocol uses client-server architecture for the communication between the tester and server. Once the tester sends the request, it can be forwarded to the other node in the ECU. Then the server responds back with positive or negative acknowledgments. The first byte in the diagnostic frame is the error identifier which specifies error from various diagnostic services. The transport protocol that UDS use is ISO-TP (Transmission Protocol). The ISO-TP is a standard and international protocol for transmitting data over the CAN protocol with the maximum frame length of 4095 bytes in a single frame.

C. UDS Over Ethernet

The number of ECU's in the vehicle is increasing rapidly. Once the ECU installed in the vehicle, it is difficult to check each and every ECU in the system by manually. For this purpose diagnostic protocols are developed in the top layer of the system. This layer will communicate with the lower layer and get the data. Diagnostic trouble code is used to find the error location in the ECU. Each module in the system has different DTC's code. These code are stored in the non- volatile memory for the later uses. There are some DTC's code which are notified by the telltale during the run time of the system like Engine temperature , Braking system , coolant system and oil pressure where the action should be taken by the user as soon as possible. The unified diagnostic service protocol is called as "unified" because it can communicate on any bus system in the network. It is not a manufacturer specific, it is an international standards to help the tester where the error have occurred.

Same like interrupt priority, there are two levels in the diagnostic services. One is soft real-time application where action can be taken later which includes systems like air conditioning cooling, infotainment system and Body Control Module (BCM). The other is hard-real time application where the action should be taken as soon as possible. It's critical in nature or else leads to human harm and breakdown of the vehicle.

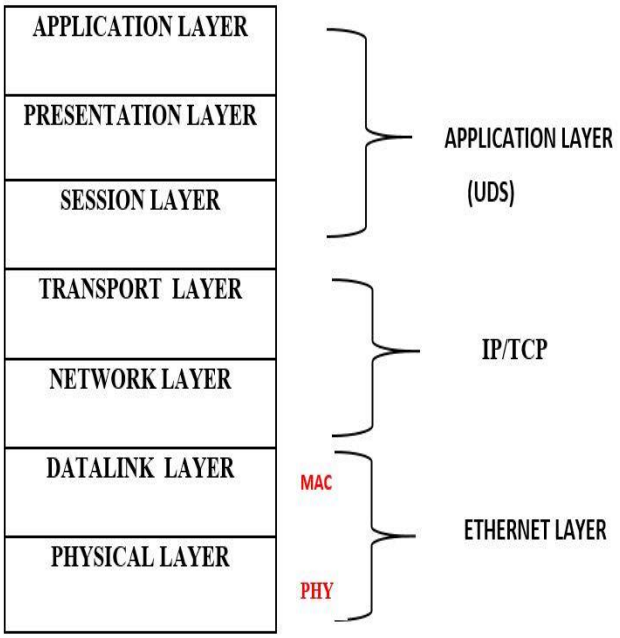

Fig. 7:- UDS Over Ethernet

The Fig.7, shows the OSI & ISO model of the UDS Over Ethernet system. The layer works on the physical , data link and application layer of the OSI model. All hardware related thing are handle by the physical layer ,then data link layer handles the data that is to be transmitted and received by the system. Whether the communication should be full or half duplex will take care by the communication layer.

UDS is present in the top of OSI model. It is located in the application layer. If the application needs better bandwidth, with the data rate of 100Mbps. Then it is better to choose Ethernet as the communication medium in the vehicle system.

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IV. SUMMARY

The implementation of different types of diagnostic services are explained in the paper. The OBD was primarily established for the vehicle emission check purpose. Later it was advanced to be used in both emission and the non- emission related real-time applications. OBD is developed to communicate over the CAN protocol only. The diagnostic service that connect over all the communication bus system is the Unified Diagnostic Service. The UDS can communicate over any protocols like CAN, LIN, Flex ray and Ethernet. Commonly UDS uses CAN as the communication protocol because of its quick response and less complexity. Due to increase in number of ECU's , there is rise in the number of DTC's for more precision and accuracy. Therefore more volume of data needs to be transferred, so large amount of bandwidth is required for communication. For this purpose UDS over Ethernet is used. Ethernet can transfer data rate of up to 100Mbps, which is useful to upload and download the data quickly.

REFERENCES

[1]. Tindell, Hansson and Wellings, "Analysing real-time communications: controller area network (CAN)," *1994 Proceedings Real-Time Systems Symposium*, San Juan, Puerto Rico, USA, 1994, pp. 259-263.

[2]. H. Kopetz, W. Elmenreich and C. Mack, "A comparison of LIN and TTP/A," *2000 IEEE International Workshop on Factory Communication Systems. Proceedings (Cat. No.00TH8531)*, Porto, Portugal, 2000, pp. 99-107.

[3]. N. Navet, Y. Song, F. Simonot-Lion and C. Wilwert, "Trends in Automotive Communication Systems," in *Proceedings of the IEEE*, vol. 93, no. 6, June 2005, pp. 1204-1223.

[4]. L. Lo Bello and O. Mirabella, "Analysis and comparison of different interconnection solutions for switched Ethernet networks," *2000 IEEE International Workshop on Factory Communication Systems. Proceedings (Cat. No.00TH8531)*, Porto, Portugal, 2000, pp. 221-230

[5]. P. Pedreiras, L. Almeida and P. Gai, "The FTT-Ethernet protocol: merging flexibility, timeliness and efficiency," *Proceedings 14th Euromicro Conference on Real-Time Systems. Euromicro RTS 2002*, Vienna, Austria, 2002, pp. 134-142.

[6]. J. Scharbarg, M. Boyer and C. Fraboul, "CAN-Ethernet architectures for real-time applications," *IEEE Conference on Emerging Technologies and Factory Automation*, Catania, 2005, pp. 8 pp.-252.

[7]. M. Rahmani, K. Tappayuthpijarn, B. Krebs, E. Steinbach and R. Bogenberger, "Traffic Shaping for Resource-Efficient In-Vehicle Communication," *IEEE Transactions on Industrial Informatics*, vol. 5, no. 4, Nov. 2009 ,pp. 414-428.

[8]. P. Kharche, M. Murali and G. Khot, "UDS implementation for ECU I/O testing," *2018 3rd IEEE International Conference on Intelligent Transportation Engineering (ICITE)*, Singapore, 2018, pp. 137-140.

[9]. Marscholik, C. and Subke, P. "Road Vehicles Diagnostic Communication Technology and Applications". Laxmi Publications Ltd. ,2009, pp 105-145.

[10]. H. Lajmi, A. M. Alimi and S. Ajili, "Using Ethernet Technology for In-Vehicle's Network Analysis," *2013 Fifth International Conference on Computational Intelligence, Communication Systems and Networks*, Madrid, 2013, pp. 353-358.

[11]. R. Darloşan, I. Marghescu and C. Lica, "Intra-car communications and diagnostic solutions," *2016 International Conference on Communications (COMM)*, Bucharest, 2016, pp. 341-346.

[12]. Aidong Xu, Lili Liu, Yan Song and Ya Zhou, "Research and development of vehicle fault diagnostic protocol ISO15765," *Proceedings 2011 International Conference on Transportation, Mechanical, and Electrical Engineering (TMEE)*, Changchun, 2011, pp. 1241-1245.

[13]. A. X. A. Sim and B. Sitohang, "OBD-II standard car engine diagnostic software development," *2014 International Conference on Data and Software Engineering (ICODSE)*, Bandung, 2014, pp. 1-5.

[14]. P. Kulkarni, P. K. Rajani and K. Varma, "Development of On Board Diagnostics (OBD) testing tool to scan emission control system," *2016 International Conference on Computing Communication Control and automation (ICCUBEA)*, Pune, 2016, pp. 1-4.

[15]. M. Wajape and N. B. Elamana, "Study of ISO 14229-1 and ISO 15765-3 and implementation in EMS ECU for EEPROM for UDS application," *2014 IEEE International Conference on Vehicular Electronics and Safety*, Hyderabad, 2014, pp. 168-173.

[16]. J.Bell, "Network Protocols Used in the Automotive Industry", Technical report, SoftFMEA, Aberystwyth University, 2002.

[17]. R. Bruckmeier, "Ethernet for Automotive Applications", Freescale Technology Forum, 2010.

[18]. Charles E.Spurgeon, "Ethernet: The Definitive Guide" , 1st Edition February 2000.

[19]. E. Matzols, "Ethernet in Automotive Network", Thesis report, Kungliga Tekniska Högskolan (KTH), 2011.