A Survey on Automotive Diagnostics Protocols

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Abstract— An automobile is a complex system that has undergone over a century of evolution. Modern vehicles have Electronic Control Units (ECU) which computing devices that control set of electronic systems or subsystems. As there was increase in number of electronic components increased inside the vehicle, maintaining proper functioning of these components is a must. For this purpose diagnostics are used. Diagnostics involve remote execution of routines, or services, on ECUs. A diagnostic tester is used for check the implementation of Diagnostics in ECU's. A Diagnostic protocol is used to describe communication between different ECU's or ECU and a tester. There are many diagnostics protocols available now. This paper presents a survey on need of different diagnostics protocols, their uses.

Index Terms— Diagnostic Protocol, Automotive Communication Bus, Automotive Diagnostics, CAN, KWP, UDS, OBD

1 Introduction

Modern automobiles consist of more than 70 ECUs for various tasks Each ECU or a group of ECU will perform specific tasks. The input for such computing devices comes from multiple sensors or actuators placed inside the vehicle. For communication to happen between the ECUs, Vehicle bus provides specialized communication network for information exchange between components inside the vehicle. These vehicle buses must assure for message delivery, non-conflicting messages, and minimum time of delivery of messages and must be cost effective. Some of the popular Vehicle bus standards are CAN (Controller Area Network), LIN (Local Interconnect Network), FlexRay etc. Whenever there is an abnormal functioning of the ECU, an error code indicating the problem which is named Diagnostics Trouble Code (DTC) is stored in EEPROM of an ECU for later retrieval. Diagnosing a vehicles problem and fixing them can be done through professional automobile diagnostics centers. Diagnostic Tools are the one which reads data (DTC's) from the EEPROM to analyze the cause of failure. Diagnostic data are located in the memory of an ECU are inspected or modified by the tester.

The word Diagnostics means identifying the cause of a problem or a situation which leads to the creation of a problem. Automotive diagnostics is a way to identify flaws in overall functionalities of a given vehicle.

1.1 Diagnostics Protocol

Protocol is a set of rules of communication that has to be followed by the end points. When the communication happens between two ECUs, some sort of protocol is used for Diagnostics purposes are Diagnostics Protocol. The automotive industry has come up with Diagnostics protocols like K-Line, UDS (Unified Diagnostics Services), and KWP (Keyword Protocol) and so on. For communication between ECU and diagnostic tool, Diagnostic session acts as a basis. During 'Diagnostics' the ECU being analyzed is in a particular session. When the interactions happen between ECU and a diagnostics tool, Diagnostics session acts like a basis. During 'Diagnostics' the ECU is being analyzed for a particular session. There are different sessions available in diagnostics. A default session is the initial session that runs in a vehicle when an ECU is powered up. One's request is received from the diagnostic tool; ECU will be switched to the Extended Diagnostic Session. After receiving the ECU programming session start request from the Diagnostic tool, further switching happens to ECUs programming session.

Diagnosing a vehicle to fix a problem in car can be done through a professional automobile diagnostic center. Diagnostic Service uses the read command for retrieving the information from ECU and the write command to write/program the data to the ECU.

2 Automotive Communication Standards

There are multiple ECU's in the vehicle and may need to communicate with each other to share information like sub routines, diagnostic trouble codes etc. For such communication to happen there is need of communication medium. Vehicle bus provides specialized communication network for information exchange between components inside the vehicle. These vehicle buses must assure for message delivery, non-conflicting messages, and minimum time of delivery of messages and must be cost effective. Some of the popular Vehicle bus standards are CAN (Controller Area Network), LIN (Local Interconnect Network), FlexRay etc.

CAN is a message based protocol basically designed for multiplex electrical wiring within automobiles. LIN is a serial network protocol used for communication between components in vehicles and is a cheap serial network that can implemented in the car while the CAN bus was too expensive to implement for every component in the car. LIN network follows master-slave communication. There are multiple slaves possible. The communication is initiated from the Master and ends with at least one slave replying. LIN has bit rates ranging from 1 kbps – 20 kbps. It is useful for less demanding applications such as operating seat motors and door locks. FlexRay has similar functionality as CAN but more faster, scalable, reliable and costly than CAN. FlexRay provides error-tolerant communication mode that is designed to meet growing safety related challenges in the automobile industry. This technology is mainly concentrates for data communication in very safety critical use areas in automobile.

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2.1 CAN bus (Controller Area Network)

A Controller Area Network (CAN bus) is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other. Can bus networks are common for cars built after 1995. They simplify wiring, improve reliability, and let vehicles self-diagnose the problems. Safety and convenience features rely on CAN bus for the easy exchange of data across the array of computers and sensors scattered around the car. At its simplest level, it can be thought of as a means of linking all of the electronic systems within a car together to allow them to communicate with each other.

CAN was developed in 1985 by Bosch for in-vehicle networks. The protocol was officially released in 1986 at the Society of Automotive Engineers (SAE) conference in Detroit, Michigan. The first CAN controller chips, produced by Intel and Philips, came on the market in 1987. The 1988 BMW 8 Series was the first production vehicle to feature a CAN-based multiplex wiring system. Bosch has published several versions of the CAN specification and the latest is CAN 2.0 published in 1991. In olden days, automotive manufacturers were using point to point wiring systems to connect electronics devices in the vehicle. As the number of electronic devices increased, the structure became more complicated. This illustrated the need for dedicated wiring in-vehicle networks, which reduced wiring cost, complexity and weight. Hence, CAN emerge as standard in-vehicle network.

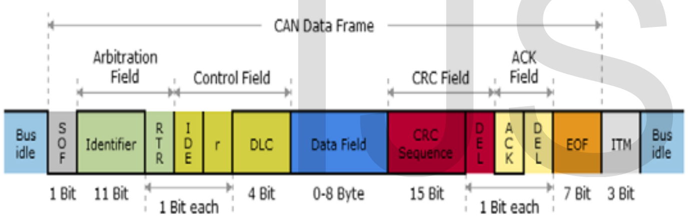

Figure 1: CAN Message Format

The CAN bus has a message based protocol. Each node can send a message independently from the status of the other nodes. If two nodes send their message at the same time, the message with the higher priority gets access to the bus line. Each node has its own unique address on the network. This allows the node to receive the inputs and data it needs to function, while ignoring information intended for other modules that share the network.

The CAN standard has a "base frame" format for the data. This base frame has following fields. It has a Start of frame bit which is a beginning bit. Followed by Identifier, An 11 bit code indicating type of data message. Remote transmission request is a priority code. IDE, A dominant single identifier extension (IDE) bit means that a standard CAN identifier with no extension is being transmitted followed by R0, which is a reserved bit. DLC, A 4-bit data length code (DLC) contains the number of bytes of data being transmitted. Followed by 0 to 8 bytes of actual data. CRC, Cyclic Redundancy Check which is some more bits to verify the information. ACK, each node acknowledges (ACK) the integrity of its data. ACK is 2 bits, one is the acknowledgment bit and the second is a delimiter and EOF Indicating the end of frame.

ECUs will broadcast messages and other ECUs that are interested using CAN ID The one which is interested will listen for those messages and ignore the rest. The messages sent in CAN are typically used for communication from mechanic's tools to ECUs to perform actions or get diagnostic information. These messages are formatted along ISO standards 14229 or 14230. CAN frames are limited to 8 bytes of data. To overcome this limitation, the ISO 15765-2 standard, often called ISO-TP is used. This standard allows us to send data into multiple frames.

3 Automotive Diagnostics Protocols

In the past, the automotive industry has seen improvements in the area of bus systems, data communication, and diagnostic protocols and so on. Based on requirements of the vehicle systems the automotive industry has developed different communication standards for information exchange between external test equipment and ECU. These standards are usually known as Diagnostic Protocols. Some of these communication standards are KWP2000, OBD and UDS.

3.1 Keyword Protocol

Keyword Protocol 2000, more often known as, KWP2000, is a communications protocol used for on-board vehicle diagnostics systems (OBD). This protocol is based on ISO 14230 standards and falls in the application layer of the OSI reference model and also covers session layer functionalities like starting, maintaining and terminating a communication session. KWP2000 also extend support for the diagnostics and flash programming for a large number of ECUs. Most of the European countries use the KWP2000 on K-Line protocol as the first standardized diagnostic protocol in a large scale. The protocol was able to communicate with large numbers of ECUs on the bus provided it was used in an environment where single ECU or very little number of ECUs was present. KWP2000 on K-Line covers all the OSI reference model layers starting from the physical through the transport layer protocols for diagnostic services.

KWP2000 on CAN is based on ISO 15765 and covers layers 3 to 7 of the OSI reference model. Therefore it supports all higher layer protocols starting from the transport layer to the application layer protocols to diagnostic services. A few years back KWP2000 on CAN was used in large scale, but gradually it was replaced by UDS protocol. Today KWP2000 is no longer used in the automotive sector except in some of the heavy duty diesel vehicles.

3.2 On Board Diagnostics (OBD) Protocol

Based on ISO 15031 standards the On Board Diaznostics (OBD) protocol is used to read the information that is being transmitted to and fro from electrical systems or subsystems of a vehicle. OBD in its various versions has been used in cars for many years. This standard supports most of the functionality

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of CAN-TP. OBD communication is carried via sending requests and receiving responses from the ECU. The OBD protocol is used for reading basic vehicle data. Society of Automotive Industry has proposed higher protocol layers for CAN. The aim is to develop standard communication mechanisms for vehicles, regardless of OEM, engine/transmission manufacturer and test system manufacturer. Hence UDS protocol was developed which is based on KWP2000. Basically the protocol implements the ISO 14229 services over CAN and allows diagnostics to control in vehicle ECUs.

3.3 Unified Diagnostics Service (UDS) Protocol

UDS is an International Standard that elaborates the individual properties which are different from data link layer requirements of an automotive diagnostic service in a road vehicle. Basically it covers the implementation details of ISO 14229 services over CAN. The standard is based on Open Systems Interconnection (OSI). The services used by a diagnostic tester (client) and an ECU (server) are differentiated as: Unified diagnostic services (layer 7) and Communication services (layers 1 to 6).

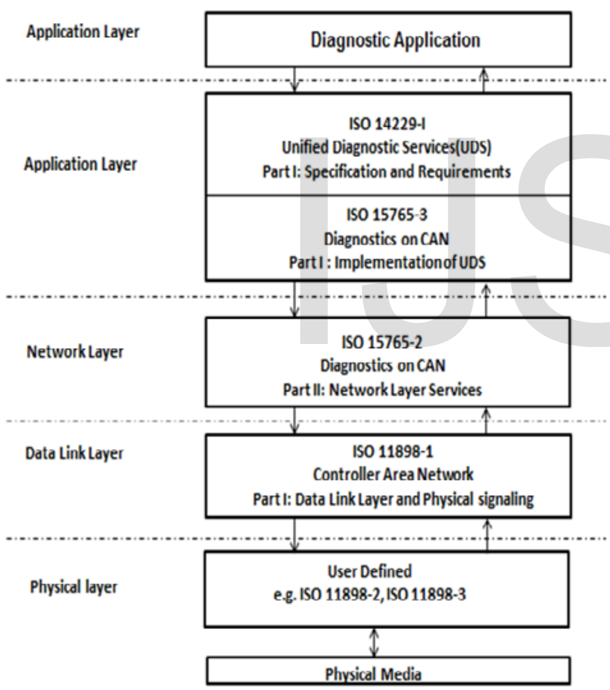

Figure 2: Implementation of UDS protocol over CAN

The main intension of UDS protocol is to communicate with all electronic data units that are placed and interconnected in the vehicle, provide maintenance as in checking for errors, actualizing the firmware, etc. In a diagnostic session, the network comprises of tester (Client) and the ECU being tested (Server). A diagnostic service request is sent from the client to the server. The client starts with a service request and always ends with positive, negative or no response from the ECU. The transport protocol of UDS consists of ISO-TP. ISO-TP is an International Standard for transmitting data over the CAN bus which allows maximum data length up to 4095 bytes in a single data frame.

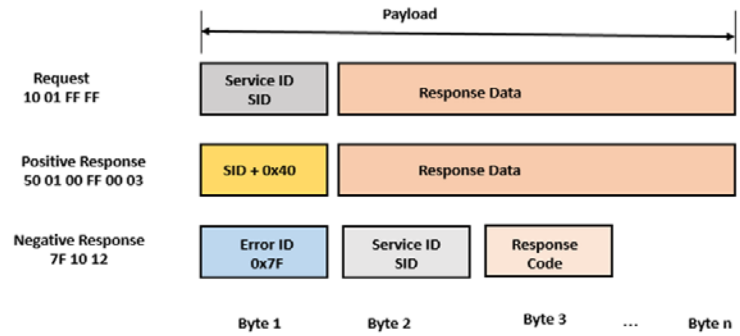

Figure 3: UDS request/response message format

The communication model between the tester and the ECU follows client-server architecture. The tester sends a diagnostic request which can be forwarded to one or more target ECUs. The ECU responds to this request by sending a positive or negative acknowledgement. In the request message first byte is the service identifier to distinguish between various diagnostic services. The remaining bytes contain sub-level identifiers, parameters and data.

Communication between ECUs follow either of two addressing methods i.e., Physical and Functional addressing. In physical addressing the interaction is point to point. The diagnostic tool communicates with a single ECU where as in Functional addressing a tester tool can communicate with multiple ECUs. Each request service shall be assigned a unique SI value. Every response to the service request assigned with corresponding unique service value. All request messages have SI bit 6 = 0. All positive response messages have SI bit 6 = 1. Each service may or may not support for the sub functions. Sub functions are used to indicate the behavior or server for particular service. Every service may or may not support for the data parameter. Data parameter includes the information that has to be sent to the server.

4 CONCLUSION

Identifying and detecting failure in the complex vehicle systems is a tedious task. But diagnostics makes it very easy. Based on the requirements from the automotive sectors, new diagnostics standards and communication technologies are introduced and used widely. This paper presents survey on the different automotive communication technologies and communication protocols.

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