



2010

L. RAY BUCKENDALE LECTURE

2010-01-2053

Merge Ahead: Integrating Heavy-Duty Vehicle Networks with Wide Area Network Services

Mark P. Zachos
DG Technologies

Presented at:
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Rosemont, Illinois, USA
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L. Ray Buckendale Lecture

This lecture, presented annually at the SAE Commercial Vehicle Engineering Conference and Exhibition, focuses on automotive ground vehicles for either on- or off-road operation in either commercial or military service. The intent is to provide procedures and data useful in formulating solutions in commercial vehicle design, manufacture, operation and maintenance.

Established in 1953, this lecture commemorates the contributions of L. Ray Buckendale, 1946 SAE President. L. Ray Buckendale, by his character and work, endeared himself to all who were associated with him. Foremost among his many interests was the desire to develop the potential abilities in young people. As he was an authority in the theory and practice of gearing, particularly as applied to automotive vehicles, it was in this field that he was best able to accomplish his purpose. To perpetuate his memory, SAE established this lecture to provide practical and useful technical information to young people involved in vehicle engineering.

The individual presenting the Buckendale Lecture will receive an honorarium and a framed certificate. All those attending the lecture will receive a copy of the lecture, and are also invited to attend a sponsored reception immediately following the lecture.



2010 Lecturer

Mark P. Zachos
DG Technologies

Mr. Mark P. Zachos is the founder and CEO of DG Technologies (DG), a company specializing in Vehicle Diagnostics and Communications Network Technology. Mr. Zachos was elected to SAE International's Board of Directors in 2010 for a three-year term, responsible for redefining SAE's strategic direction, providing leadership that links SAE's members to the operating organization and ensuring organizational performance on a macro level.

At DG Technologies, Mr. Zachos is responsible for the company's overall operating business as well as promoting, selecting, developing and integrating advanced enabling technologies that support all of DG Technologies' programs and strategic initiatives. He is also responsible for new technology "mining" and commercialization, and for the technical direction of all DG products and services.

Mark has been very active in SAE Technical Committee work for over 20 years. He is Vice Chairman of both the Vehicle E/E Diagnostics Committee and the Vehicle Systems Network Architecture Committee, and is a contributing member of the SAE Truck and Bus Communications Sub-Committee. He is also Chairman of the J2602, J2561, J2411, J2178, J1699-3, J1939-82 and J1939-84 Task Forces.

Mark has had direct involvement with the development of over 20 technical standards relating to vehicle networking; organized, authored, and co-authored dozens of technical papers and led technical sessions at the SAE World Congress and other SAE and industry events; participated with SAE and industry in the development of OBD-2 technology providing the U.S. EPA and the California Air Resources Board (CARB) with new technical standards for diagnostics of vehicle emission systems; organized an SAE TOPTEC on Future Technology for Vehicle Communications; actively recruited new SAE members; and contributed on behalf of SAE to other technical organizations including many ISO Working Groups and IEEE.

A past recipient of SAE's Forest R. McFarland Award and the Technical Standards Board Outstanding Achievement Award, Mark is extremely honored to receive the 2010 L. Ray Buckendale Lecture award. To this end, Mark's goal is to use this opportunity to detail the importance of vehicle networks not only to the commercial vehicle industry that DG Technologies is an integral part, but also to engineers and students to emphasize both practical and emerging application of vehicle networks.

55th Annual L. Ray Buckendale Lecture

Merge Ahead: Integrating Heavy-Duty Vehicle Networks with Wide Area Network Services

Mark P. Zachos
DG Technologies
2010-01-2053

This SAE technical paper presents the 55th Annual L. Ray Buckendale Lecture, which was presented during the SAE 2010 Commercial Vehicle Engineering Conference and Exhibition on October 5, 2010 in Rosemont, Illinois, USA.

Special thanks to the sponsors, organizers, chairperson, and especially the author who made this publication possible.

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Merge Ahead:

Integrating Heavy Duty Vehicle Networks with Wide Area Network Services

Mark Zachos (mark@dgtech.com)
DG Technologies President & CEO
SAE Board of Directors &
SAE J1939-84 HD-OB Task Force
Chairman

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ABSTRACT

Commercial vehicle operators have many options available to them for managing their assets. Whether in an on-highway fleet, agricultural / off-road, construction, or military, available real-time vehicle information is growing. While accessing this data via applicable Wide Area Networks (WANs) is commonplace, new technologies are just beginning to develop to take advantage of all of the connectivity possibilities to further aid in delivery of goods and services. As an enabler to expanding these fleet management applications, vehicle on-board networks (commonly referred to as “in-vehicle” or simply “vehicle networks”) are expected to support a growing number of vehicle related technological solutions.

This paper provides background on vehicle networks, including key terminology, an introduction to standards based protocols, and critical SAE vehicle network related standards. While an historical view of vehicle network topologies and a rationale for the very first vehicle networks is summarized, growth applications such as fleet management system use of vehicle network data generated is emphasized.

To provide an understanding of the importance of a vehicle network backbone, a comparison to modern local area networks (LANs) is provided, along with the structure of the data packets or Protocol Data Units (PDUs). Next, standards based vehicle networks supporting Heavy Duty vehicles are described to explain information is conveyed. These standard protocols include SAE J1708, J1587, J1939, J2534, CAN (ISO 11898), and ATA/TMC RP1210. In order to illustrate how these standard protocols work, this paper provides a detailed overview of SAE J1939 including the J1939-7 and J1939-73 standards, as well as Heavy-Duty On Board Diagnostics (HD OB) standard Messaging and Diagnostics that use J1939. The paper describes how these protocols and those related with LAN and WAN networks complement each other to provide end-to-end connectivity to support a variety of fleet management applications.

Next, the promise of leveraging integration of vehicle networks with LANs and Wide Area Networks (WANs) is discussed. While the industry has recently begun the implementation of the aforementioned internetworking, future inter-vehicle networking scenarios will be described, along with proposed standards required for implementation.

Finally, the future for vehicle networking is outlined including opportunities for standards development in the area of security, bandwidth allocation, application-specific vehicle network protocols, and emerging WANs.

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1. INTRODUCTION

The goal of this paper is to provide solid reference material for those involved in vehicle networking and, in particular, to provide basic tutorial material for young engineers just entering the commercial vehicle profession. By merging high technology on-board vehicle networks with off-board functions linked via local and wide area computer networks, numerous exciting new commercial and military vehicle communications applications have been, and will continue to be developed.

Modern Heavy-Duty (HD) vehicles are equipped with multiple Electronic Control Units (ECUs) that operate components on the truck such as engines, transmissions, brake systems, instrument clusters and lamps. The term “truck” refers not only to the tractor (cab) and trailer, but also to military and off-highway vehicles including those in the construction and agricultural industries. We will often use “HD” or “truck” to signify all HD vehicles.

ECUs need to share information in order to implement the complex control mechanisms in a powertrain system. The ECUs are also capable of performing system diagnostic functions and reporting diagnostics information to tools, such as hand held diagnostic scan tools (generically, Vehicle Diagnostic Adapters (VDAs)) or PCs, for assisting technicians with vehicle maintenance. The sharing of information is accomplished via an on-board vehicle network. HD equipment often has multiple vehicle networks, which are used for communicating both standards based information (e.g. J1939 message data) and private OEM information (proprietary data). A vehicle network linking ECUs operates in a similar manner to an office building local area network that shares information between office computers.

The following sections of this paper explain the operation of vehicle networks. This paper then describes how wireless wide area network technology, such as WiMAX and LTE (often marketed as mobile 4G networks), is utilized to communicate vehicle information from HD equipment to an office computer, or network of PCs (LAN). This “merging” of vehicle data, with applications running on office computers, enables new capabilities from remote diagnostics to improved logistics and results in better fleet operating efficiencies, cost savings, emissions improvements, and related benefits.

2. VEHICLE NETWORK BACKGROUND

A. The Need for Vehicle Networks

Why are vehicle networks needed, and how are they utilized in modern heavy duty equipment?

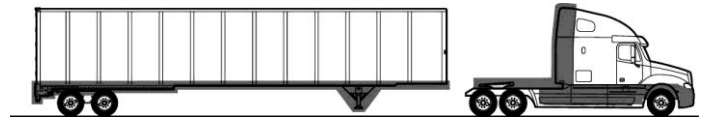


Figure 1 – Need for Heavy-Duty Vehicle Networks

As described in the previous section, although Figure 1 shows a truck cab (tractor) and trailer, we now know the HD vehicle industry includes many more elements, and industries, than this. But how does this differ from the passenger car industry?

First of all, different components (engines, transmissions, brakes, etc.) from different well-known tier one suppliers are mixed together on the same equipment. Many vehicles are customer specified, so variation abounds. Even without a custom order, a HD vehicle most often comes standard with an engine from tier one A, transmission from tier one B, and brakes from tier one C. Therefore, the HD vehicle OEM requires a communications system (i.e. vehicle network) to implement a common method of communications between all of these components. In addition, OEMs must manage their own standards based instrument cluster, body controller, and related systems. The HD industry has promoted open communications that is not proprietary, although proprietary messages may still exist. Typical documented open communications messages are: vehicle speed, temperatures, engine speed, and pressures. There are also standard system commands and diagnostic information.

A standard diagnostics interface for HD vehicles is a key enabler for the industry to link on-board functions to off-board devices. Later in this paper we will provide information on vehicle diagnostics interfacing, and an overview of emerging HD-OB (On Board Diagnostics), and the off-board interface RP1210 API.

There are distinct systems that come together to form a common vehicle diagnostics network system. Figure 2 identifies each element of the in-vehicle network system beginning with the onboard vehicle/equipment communications side and moving to Original Equipment Manufacturer (OEM) or component manufacturer diagnostic applications.

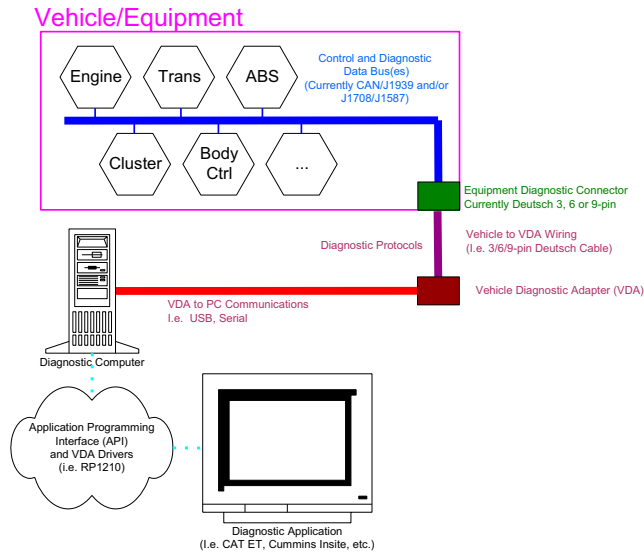


Figure 2 - Vehicle/Equipment Data Bus Architecture and Diagnostic Connectivity

B. Introduction to Standards-Based Protocols [Ref 18]

i. SAE Technical Standards Committee Overview

SAE International supports the development and publication of vehicle standards under the direction of the Technical Standards Board (TSB). SAE's TSB has organized several Councils that focus on specific industry groups. In the TSB's Truck and Bus (T&B) Council, for example, work focuses on HD On-Highway Vehicle standards. Also, under the T&B Council, many Technical Committees exist in which the actual work of standards writing is accomplished. These Technical Committees are responsible for the preparation, development and maintenance of all relevant technical reports within their scope. Technical Committees consist of technical experts from government, industry, regulatory agencies and academia.

The following is a list of some of the Technical Committees reporting to the T&B Council.

- Hybrid Communications Network for Power Management
- Hybrid Safety
- Hybrid Energy Storage
- Hydraulic Hybrids
- Electrical/Electronic Advisory Group
- Low Speed Communications Network
- Control and Communications Network

- Event Data Recorder
- Electrical Systems
- Brake and Stability Control Advisory Group
- Foundation Brake
- Brake Actuator
- Brake Systems
- Wheel
- Stability Control Systems
- Air Brake Tubing & Tube Fittings
- Aerodynamics/Fuel Economy
- Tire

The types of Technical Reports generated by these Committees are:

- **SAE Standards:** These Technical Reports are documentations of broadly accepted engineering practices or specifications for a material, product, process, and procedure or test method.
- **SAE Recommended Practices:** These Technical Reports are documentations of practice, procedures and technology that are intended as guides to standard engineering practice. Their content may be of a more general nature, or they may propound data that have not yet gained broad acceptance.
- **SAE Information Reports:** These Technical Reports are compilations of engineering reference data or educational material useful to the technical community.

ii. The ISO

Another standards organization actively working on vehicle networks is the International Organization for Standardization (termed "ISO" for its French acronym), based in Geneva. The following is an overview of the scope of work being done in the ISO/TC22/SC3/ WG1 (Working Group):

- Standardization in the field of data communication and diagnostic communication
- Observation of worldwide OBD regulation
- Harmonization of national and international OBD standards
- Related data access and transmission security issues
- Data transmission between road vehicles and off-board diagnostic devices.

Their role also includes the proposal of new standards where necessary and appropriate. This may include globalization of

a national standard, whether from the automotive industry in Germany (Verband der Automobilindustrie or VDA), SAE International or other standards organizations. In fact, vehicle related standards are only one small component of ISO standards, which also include data communications, telecommunications, and many other areas of standardization.

*iii. The American Trucking Association (ATA)
TMC Recommended Practices*

The mission of the American Trucking Associations (ATA), Inc. is to serve and represent the interests of the trucking industry. The ATA has organized several Councils to serve the industry. One of the Councils related to vehicle network technology is their Technology & Maintenance Council (TMC). Another council that is related to data communications and use of information technology is their Information Technology & Logistics Council (ITLC).

Concentrating on the TMC, their purpose is to improve transport equipment, maintenance and maintenance management. The Council develops Recommended Engineering and Maintenance Practices "RP"s that are voluntarily adopted by fleets, OEMs and component suppliers. For example, the RP1210 document is a standard diagnostics Application Programming Interface (API) RP developed by TMC's S.12 Onboard Vehicle Electronics Study Group.

This nomenclature is commonplace, specifically calling something that may be thought of as a "standard" something other than the term "standard". Here a Recommended Practice or RP is no different than how much of the Internet has been built, not based upon standards, but instead RFCs or "Request for Comment". The Internet Engineering Task Force, IETF, develops RFCs which do gather many industry comments, which are resolved over time and slowly the RFC is commonly adopted as a standard way to perform some capability.

iv. The IEEE

The Institute for Electrical and Electronics Engineers, Inc. (IEEE), a non-profit organization, is a worldwide leader in the advancement of technology. It is a leading authority in subjects ranging from aerospace systems, computers, and telecommunications to biomedical engineering, electric power, and consumer electronics. As of early 2009, IEEE had over 1000 active standards and more than 400 standards under development. Its membership includes 39 societies organized into five technical councils (Electronic Design Automation, Superconductivity, Nanotechnology, Sensors,

and Systems) representing a wide range of technical interests. For example, the IEEE Sensors Council comprises 23 societies with a combined membership of 260,000 as of early 2007.

The work of one Council and one Technical Society are of particular interest to automotive engineers. The IEEE Vehicle Technology Society is concerned with land, airborne, and maritime mobile services; portable, commercial, and citizen's communications services; vehicular electro-technology, equipment and systems of the automotive industry; and traction power, signals, communications, and control systems for mass transit and railroads.

Many IEEE Standards influence the design, testing, and operation of HD systems. These include Standards related to power and energy, instrumentation and measurement, mobile and stationary batteries, nanotechnology, telecommunications, and transportation safety, especially highway communications and rail safety. One relevant standard to this paper is the IEEE 1609 standard set now under development. IEEE 1609 is a set of documents that specify vehicle Dedicated Short Range Communications (DSRC) primarily for safety systems applications. An in-vehicle network interface message set which would link to the DSRC system is defined in SAE J2735.

Such standards development implies that vehicle data is destined to travel beyond the vehicle, via standard two-way communications methods. Whether DSRC, WANs, or LANs; standards will "pave the way" for interaction from, and to, HD and other vehicles.

v. United Nations Economic Commission for Europe (UNECE)

The objective of the UNECE is to foster sustainable economic growth in, and among, its member countries. UNECE provides a forum for communication; brokers international legal instruments that address trade, transport, and the environment; and provides statistics, economic and environmental analysis.

The United Nations' Economic and Social Council set up the UNECE in 1947. It is one of the five regional commissions of the United Nations. Its 56 member countries are located in the EU, non-EU Western and Eastern European countries, southeast Europe, the Commonwealth of Independent States, and North America. Over 70 international professional organizations and other non-governmental organizations take part in UNECE activities.

UNECE has quite a history when it comes to road vehicles, as their UNECE WP.29 Working Party on Road Transport Vehicles (WP.29) is now working on issues relating to vehicle networks.

WP.29 was established in 1952 as the Working Party on the Construction of Vehicles under the Inland Transport Committee of UNECE. In March 2000, WP.29 became the “World Forum for Harmonization of Vehicle Regulations (WP.29).” The objective of WP.29 is to initiate and pursue actions leading towards worldwide harmonization and development of technical regulations for vehicle safety, environmental protection, energy efficiency, and anti-theft performance.

In 2001, WP.29 decided that there should be a Global Technical Regulation (GTR) dealing with HD vehicle emission diagnostics systems. The group working on the GTR is referred to as WWH-OBD (World Wide Harmonization of OBD). The ISO 27145 document now under development supports the WWH-OBD vehicle diagnostics communications requirements.

3. HISTORY & TOPOLOGIES – VEHICLE NETWORK PROTOCOLS AND STANDARDIZATION

Today, it is common for a fleet to custom order a truck, bus, construction, or agricultural HD vehicle of OEM “Brand X” with an engine of “Brand E”, a transmission of “Brand T” and an ABS brake system of “Brand B”. This even occurs though OEM “Brand X” may have an intimate business affiliation with, or even own, the engine, transmission, and/or brake manufacturer.

This is in contrast to passenger car OEMs. While their standards are open, actual implementations are not quite as open. Because of high volume and vertical integration, passenger car OEMs often feel free to deviate from industry standards for reasons of competitive advantage or convenience. In the automotive OEM world, there is no equivalent situation for vehicle systems to be assembled with competitive components as is common in the commercial vehicle world. Buyers cannot custom order engine, transmission, and braking systems from companies other than those the OEM offers. Vehicle network interfaces for automobiles, therefore, may represent simplified design and selection alternatives available to the customer.

In the 1980's, requirements for vehicle emissions reduction and cleaner air brought government involvement leading to legislated On-Board Diagnostics (OBD) standards. This required use of a common vehicle communications interface. This happened at a time when the automotive companies

started development and use of networked electronic components. This allowed them to utilize the required OBD system for customer service diagnostic access. As OBD regulations evolved, standards (such as SAE J1962 Diagnostics Connector and SAE J2012 Diagnostics Trouble Codes) for interfacing test equipment to vehicles were developed by SAE International. While on the automotive front, SAE standards development has been limited to supporting OBD emissions regulations and has not been expanded to include non-emissions system component communications, the scope of J1939 for HD vehicles has expanded to include other areas of interest.

Although clean air requirements for the HD industry came several years later than those for passenger cars, the heavy-duty truck and bus industry has voluntarily moved ahead to adopt standards that ease mixing and matching of on-vehicle network components. In fact, one of the heavy-duty industry voluntary standards, SAE J1939, has been accepted by the U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) as an approved OBD protocol. SAE J1939 is also a standard that defines an in-vehicle (serial) network used to communicate control and status information between Electronic Control Units (ECUs) on a HD vehicle. The following sections will now explore the function of in-vehicle network serial communications.

A. Wire Harness without Serial Communications

In the “old days”, wire harnesses were simple links between the various electrical components of a vehicle. Figure 3 shows a typical 1940's vehicle wire harness connector. The number of connections in the vehicle used for power and control (data) were usually less than 100.

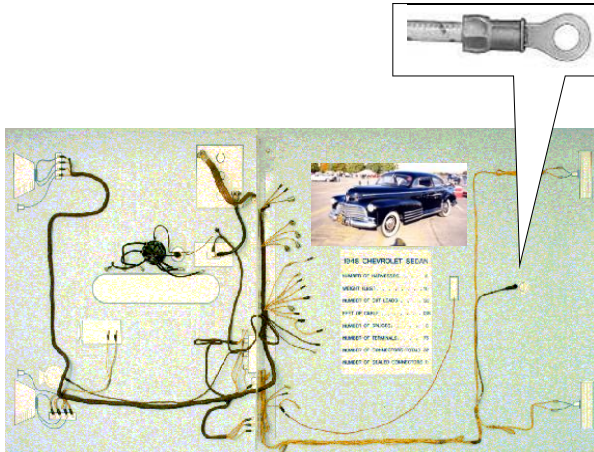


Figure 3 - 1940's Vehicle Wire Harness Connector

B. Vehicle Network Topologies for Today

Figure 4 shows an example of a modern automotive wiring harness. It is much more complex. This vehicle harness has more than 6400 terminals and up to 500 connectors. The total harness may consist of a significant length of wires and can be very heavy. These harnesses include the vehicle network's hard wire (physical layer) that carries data signals between nodes (ECUs).

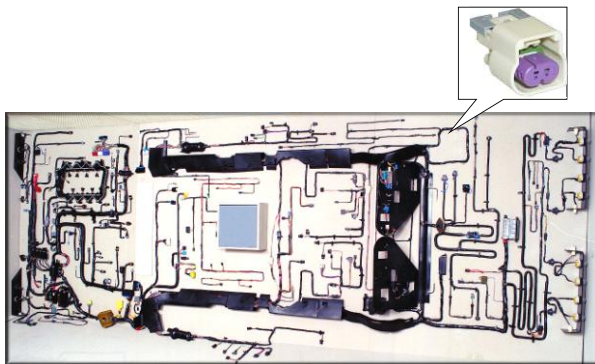


Figure 4 – Today's Typical (Automotive) Vehicle Wire Harness

The topology of a vehicle network can vary, depending on the network application. A Ring topology, Figure 5, is typically used for networks requiring redundant connections in mission critical applications.

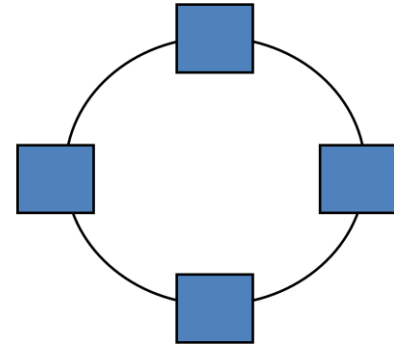


Figure 5 –Ring Network Topology

A Star topology, Figure 6, is typically used in less complex, often lower cost applications.

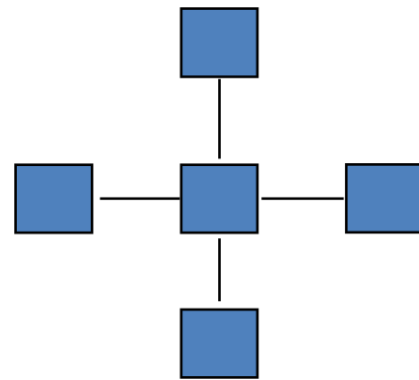


Figure 6 –Star Network Topology

In network applications with nodes operating as “peer-to-peer”, any node is allowed to communicate with any other node. For this architecture, similar to the world of LANs and Ethernet, the Bus topology is commonly used. Note that the Controller Area Network or CAN protocol, a mainstay of vehicle networks, is a Bus topology design, Figure 7.

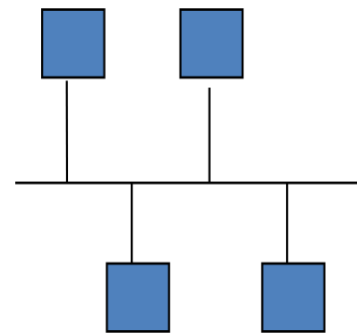


Figure 7 –Bus Network Topology used by the CAN Vehicle Network Protocol

C. Vehicle Network Protocol Features

What vehicle network features must to be supported to handle today's HD vehicle network environment, applications, and emerging uses? Although this is easily the subject of another paper on that specific subject, the following are typical features that are specified for all vehicle network applications.

- Message assignments for each node
 - Data Transmitters
 - Data Receivers
- Message error checking methods
- Dominant and Recessive States (network voltage levels)
- Message Frame Configuration
 - Header descriptor
 - Message priority
- Bus Arbitration Method
 - Destructive, Non-Destructive
- Large Message Transport Mechanism
- Parameters for Data
 - Length
 - Bit Resolution And Offset
 - Broadcast Rate
 - Periodically
 - As Necessary
 - On-request

For example, the bus arbitration method from the list above describes how a device obtains access to the network on a timely basis. This is important in determining how to architect a network. Critical vs. non-critical applications, must be prioritized. This becomes more important as data travels to and from a vehicle. As a point of reference, let's discuss something everyone is familiar with, a LAN using an Ethernet network. Whether at home or work, devices utilize a CSMA/CD (Carrier Sense Multiple Access/Collision Detect) protocol at the OSI layer 2 (more on this later) to determine which device has access to the single Ethernet network. Since two or more stations share this common transmission medium (a LAN's Category 5 Cabling or Wi-Fi).

To transmit a PDU of data or information, a node must wait for an idle period on the medium when no other station is transmitting. It then transmits the frame by broadcasting such that it is "heard" by all the other stations on the network. If another device tries to send data at the same time, a "collision" occurs. After a reset frame, an algorithm called "truncated binary exponential back off" is used to generate a random time to retransmit, avoiding another collision.

Similarly, Vehicle Networks use protocols and specific methods to send information and recover from collisions, all referred to as bus arbitration.

4. HD VEHICLE NETWORK PROTOCOLS

A. J1708/J1587: Low Data Rate (Speed) HD Vehicle Network ^{[Ref 1] [Ref2]}

SAE International Technical Standards Committees have been active for over 25 years developing vehicle communications specifications for Automotive Passenger Vehicles and Heavy-Duty Commercial Vehicles. Network specifications have been developed for different types of vehicles (e.g. light duty or heavy duty) as well as for different networks applications on the vehicle (low data rate diagnostic applications, high data rate control applications, etc.). Many modern vehicles will have more than one network to support different on-board applications.

After the success that the automotive industry enjoyed with the advent of vehicle computing devices (i.e. ECUs) for increasing networked functionality and meeting emissions requirements, the HD industry followed closely behind with the "physical layer" (Figure 8, Layers 1 & 2 "Physical and Data Link Layers", SAE J1708) and a corresponding set of standardized messages defined in SAE J1587 (Figure 8, Layer 7 "Application Layer"). These two documents commonly referred to together as J1708/J1587 protocol, were developed as a joint effort between the American Trucking Association's Technology & Maintenance Council (TMC), and SAE International.

Besides solving some of the vehicle network challenges of the day, SAE J1708 and J1587 provided a very good learning experience for managing system interface issues. The development process helped engineers identify the problems that would need to be solved in future vehicle networks.

• Most Commonly Found in HD World

7	Application	Diagnostic Apps, Transfer a File, Send Messages
6	Presentation	Handles File Format Differences
5	Session	Provides Synchronization of Data Flow
4	Transport	Provides End to End Delivery
3	Network	Switches and Routes Information (E.G. Router)
2	Data Link	Delivers Information to the Next Node
1	Physical	Transmits Bit Stream on Physical Medium

Figure 8 – The Open Systems Interconnection (OSI) Model upon Which Most Network Standards Are Based

Due to its fairly low speed (9.6Kbps), SAE J1708/J1587 is not considered a preferred “control” network today, but it remains in use as an information-sharing and diagnostics network. Ten years ago it was predicted that it would be gone in ten years. It will, however, most likely be here for another ten years, as it is slowly being replaced by newer, faster general-purpose, and even slower specific-purpose network protocols.

The following are defined in the SAE J1708/J1587 protocol and are typical structures and functions that are defined for most vehicle network protocols.

- Priority - 3 Bits (0 = Highest, 7 = Lowest)
- MID (Message Identifier)
 - Engine, Transmission, Etc
- PID (Parameter Identifier)
 - Vehicle Speed, Engine Speed, Etc.
 - Packed PIDs
- Destructive Bus Arbitration
- Checksum
 - Mathematical Validation (Good Message / Bad Message)
- Diagnostic Fault Codes
 - Active Faults, Inactive Faults
- Active Diagnostic Codes:
 - Indicate A Fault Is Presently Occurring
 - Check Engine Light, ABS Light
 - MIL – Malfunction Indicator Light
 - No Lights Defined By J1708/J1587
 - Left Up To Instrument Cluster Software
- Inactive Codes:
 - Not Presently Occurring, But Has Been Detected;
 - The Conditions To Create The Fault Are Not Present “Right Now”
 - Clearing Inactive Faults
 - Possible Only To Clear “Inactive” Faults
 - SID (Subsystem Identifier)
 - Problem With A Component (e.g. fuel injector)
 - FMI (Failure Mode Indicator)
 - “Shorted High”, “Data Above Normal”, Etc.
 - Occurrence Count
 - How Many Times Has This Fault Happened?

B. The CAN Protocol

Searching for a higher speed network to support modern HD vehicle power-train control applications, the SAE determined that the Bosch Controller Area Network (CAN) protocol could be adopted for its requirements.

The International Standards Organization (ISO) has adopted the CAN protocol as a standard for high speed data communications (ISO 11898-2). A summary of the CAN protocol features follows.

- CANID description (the CAN Identifier)
 - 11-bit CANID = “Standard CAN”
 - 29-bit CANID = “Extended CAN”
 - (J1939 Uses “Extended CAN”)
- Error Checking
 - Bit Stuffing Rule
 - No More Than Five Consecutive 1s Or 0s
- Non-Destructive Bus Arbitration
 - Nodes may transmit many different messages
 - Each message has an unique priority assign to it via software
 - Bus arbitration occurs when 2 or more nodes transmit a message at exactly the same time.
 - The message with the highest priority wins the arbitration and its message transmission succeeds, the others fail and will retry.
- Outstanding Error Detection Capability
- No Master or Slave control module
 - All nodes communicate Peer to Peer.
- All nodes see all messages on network at the same time.
- 0 to 8 bytes of data per CAN frame.
 - This can be changed dynamically by software.
- Network needs two nodes to operate.
 - An off board diagnostic tool can normally act as a node.

The features noted above describe the Data Link Layer (Figure 8, Layer 2) of a vehicle network, but are not a complete protocol definition. Vehicle networks also require definitions for an Application Layer (i.e. messages, Layer 7, Figure 8) and Physical Layer (Layer 1, Figure 8). SAE therefore added those missing protocol layers by when incorporating CAN into the new SAE J1939 specification.