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A New Vehicle Data Bus Architecture and IVIS Evaluation Platform for ITS Modules*

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ABSTRACT

An increasing number of ITS-related after-market systems present a set of in-vehicle installation and use problems relatively unique in the history of automobile use. Many automobile manufacturers would like to offer these new state of the art devices to customers, but are hampered by the current design cycle of new cars. While auto manufacturers are indeed using multiplex buses (the automotive equivalent of a computer local area network), problems remain because manufacturers are not converging on a single bus standard. This paper presents a new dual-bus architecture to address these problems, with an In-Vehicle Information System (IVIS) research platform on which the principles embodied in the ITS Data Bus architecture can be evaluated. The dual-bus architecture has been embodied in a proposed SAE standard, with a ratification vote in December, 1996. The architecture and a reference model for the interfaces and protocols of the new bus are presented and described. The goals of the ITS Data Bus are to be inexpensive and easy to install, and to provide for safe and secure functioning. These high-level goals are embodied in the proposed standard. The IVIS Development Platform comprises a number of personal computers linked via ethernet LAN, with a high-end PC serving as the IVIS computer. In this LAN, actual devices can be inserted in place of the original PC which emulated them. This platform will serve as the development and test bed for an ITS Data Bus Conformity Test, the SAE standard for which has also been developed.

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INTRODUCTION

An increasing number of ITS-related devices, such as navigation and route guidance (N&RG), traveler information, communications and security systems, are being offered to the motoring public. These systems present a set of installation and use problems that are relatively unique in the history of motoring and automobile use. As electronic systems, these devices are more complex than systems that might have been added to vehicles in the past, thus requiring more careful installation. Moreover, many of these devices require more complicated connections to the vehicle than merely deriving electrical power. For example, a security system requires connection to the power door locks for remote entry, and to the engine controls for remote starting. A N&RG system might require data from the vehicle's anti-lock brake system or steering system to be able to accurately place the moving vehicle on a digital map displayed to the occupants. These requirements can dramatically complicate installation of the devices, either by vehicle manufacturers or, more especially, by after-market installers. In addition, many automobile manufacturers would like to be able to offer these new state of the art devices to their customers, but are hampered by the current design cycle of new cars. OEM and third party electronics companies would like to be able to design automotive electronics for use across multiple car platforms and across auto manufacturers, but there is no single standard interface.

In addition to the data communication and power needs of individual devices, the ITS-equipped vehicle will also require that some of these devices communicate among themselves. For example, the N&RG system must communicate with the motorist services or "yellow pages" module, so that the two devices together can determine the "nearest filling station" to the vehicle's present location. In another case, a pager can send the phone number of the sender of the page, thus enabling the driver to more simply dial the number for a return call, perhaps using a voice-activated cellular phone. Ultimately, with a number of devices installed in a vehicle, there will likely be need for a high-level information manager to prevent several devices from competing for the driver's attention simultaneously, thereby providing distraction rather than help.

Modern computing paradigms embrace the concepts of network and distributed computing, and it is therefore natural to consider these concepts as one addresses the requirements of the ITS-equipped vehicle. While auto manufacturers are indeed using multiplex buses (the automotive equivalent of a local area network), problems remain because the automobile manufacturers are not converging on a single bus standard. As a result, device manufacturers must design and build multiple versions of their products to attach to the various buses, raising the cost. In addition, a device connected to the auto's multiplex bus must be qualified through the normal design cycle of the automobile, which does not easily allow unplanned-for electronics to be added by the manufacturer, the dealer, or the customer. For warranty, safety, and liability reasons, electronic devices must not be allowed to interfere in any way with the operation of the vehicle or of any of its subsystems, many of which send and receive data over the vehicle's data bus. Therefore, these devices cannot be retrofitted to the auto's multiplex bus.

A DUAL-BUS VEHICLE ARCHITECTURE

This paper describes a new architecture being developed which will address these problems, as well as a research platform on which both the principles embodied in the architecture and the information management system can be evaluated. A dual-bus architecture has been proposed (1, 2) as the basis for a family of SAE standards, in which an ITS Data Bus (IDB) is connected to the vehicle's multiplex bus through a gateway. This architecture is presented in Figure 1, which comprises three major areas: the various types of OEM automotive busses (only one of which is installed in any vehicle) are represented in the left portion, the Gateway Device in the center, and the ITS Data Bus and various sample installed devices are on the right. The components shaded in gray are manufactured and installed by the vehicle manufacturer. Each of these major components is described in the section on the Reference Model below. When implemented, this architecture will allow electronic device manufacturers to build a single automotive version of their product which can plug into the IDB in any vehicle. In addition, the IDB is independent of all auto systems, with two exceptions: DC power, and the ability to exchange limited types and amounts of data with the vehicle through the gateway. In addition to permitting easier installation of IDB-qualified electronic devices, this architecture eliminates the need for a full electrical bench qualification of new devices. Of course, maximum power drain in ignition-on and ignition-off states will have to be specified and EMC specifications will have to be met by ITS Data Bus devices. The gateway, under control of the auto company, acts as a "firewall", allowing only authorized message traffic to pass between the auto's multiplex bus and the IDB devices. This "firewall" has significant safety benefits, as it prevents ITS devices (both OEM and after-market) from interfering with basic functions of the vehicle. The various elements of this architecture will be discussed in more detail in the context of the IDB Reference Model presented below.

(Insert figure 1 about here)

THE SAE ITS DATA BUS COMMITTEE

The realization of this new vehicle architecture is the result of the collaborative efforts of a number of representatives of the automobile manufacturers, the manufacturers of both original equipment and aftermarket electronic devices, the microcomputer industry, and several national laboratories. The members of the SAE ITS Data Bus Committee have met bi-monthly for over two years, and held several workshops. These efforts have resulted in a set of proposed SAE standards which cover all aspects of the IDB, with formal balloting as an SAE standard scheduled for December, 1997. These standards are the product of a process which followed sound systems engineering principles: a needs assessment was followed by careful development of a set of functional requirements, for both the IDB and the gateway, and the final IDB and gateway configurations result from addressing the needs and functional requirements.

The overall IDB goals describe the design philosophy of the IDB rather than quantifiable specifications. Performance specifications are contained in a set of documents (3, 4, 5, 6) which comprise the ITS Data Bus Standard. Safety and security constitute two of the overriding requirements, that the ITS Data Bus provide an environment in which devices can be plugged, unplugged, and operated in a vehicle in a manner which does not threaten the integrity of the vehicle or the devices that are being used. Moreover, while not itself providing security and authentication services, the IDB will not preclude the implementation of suitable security for transactions involving the exchange of money and/or proprietary information with service providers outside the vehicle. These services might include electronic toll collection, parking payment, and credit card transactions, perhaps over the internet. It is necessary that IDB-compatible devices and software be easy to design and install, as well as being easy for the vehicle owner to use, all at an incremental cost-per-node which is under $1.00. Finally, since the scope of applications for the IDB is enormous, every effort must be made to ensure that the widest possible range of applications can be supported. Many of the applications may not have even been conceived or designed yet.

ITS DATA BUS ARCHITECTURE REFERENCE MODEL

A reference model describes a system in terms of the basic functional elements and the interfaces among them. Thus, the ITS Data Bus architecture reference model presented here does not define a physical implementation. This model was accepted by participants at both the 1995 and 1996 workshops and now forms the basis for the ongoing standards development work in the SAE ITS Data Bus Committee. Figure 2 presents the ITS Data Bus Reference Model (1, 2), which identifies the following functional elements: vehicle resources ("sources" from which information or data are derived, and "sinks" to which data and information are sent), vehicle buses, a gateway controller, the ITS Data Bus, and accommodated (end user) devices.

Vehicle Resources - There are many resources in a vehicle that could be of use to ITS device developers. These may be only information resources or they may be physical entities that are controlled by the vehicle or the ITS Data Bus devices. "Sources" include wheel ticks from ABS sensors, odometer readings, input from multi-purpose steering wheel buttons, vehicle performance data, diagnostic data, etc. The information from these sources will, if the manufacturer so chooses, be available at the gateway for use by the accommodated device. "Sinks" (recipients of information across the gateway and from the IDB) include in-dash displays, audio outputs (via the entertainment system) including radio mute functions, door look actuators, seat and mirror positioning motors, etc. Once again, access to these resources is controlled by the gateway controller at the discretion of the vehicle manufacturer.

Vehicle Buses - More and more, modern vehicles use one or more OEM multiplex buses, shown on the left of Figure 1, to integrate powertrain functions or convenience and control functions. These buses differ across vehicle manufacturers and often across vehicle platforms within a single manufacturer. These buses are "closed" in the sense that once the vehicle has been designed, and the design frozen, no new devices can be added to it. It is therefore key to the success of this standard that the gateway controller, or an interface port specifically designed to accommodate a gateway controller, be designed and installed by the vehicle manufacturer. Many of these buses are indicated by name on the left side of Figure 1.

Gateway Controller - To provide the safety functions required for the IDB, the bus must be separated from the OEM vehicle bus by a Gateway Controller, shown in the center of Figure 1. This is a logical function, not necessarily performed by a dedicated device. Its functions may be performed either by an existing module already connected to the OEM bus, such as the car radio, which is then augmented to include an interface to the ITS Data Bus, or by a dedicated module. The Gateway Controller controls the flow of information between the ITS Data Bus and the OEM Bus. It is designed to allow only OEM-authorized information from the ITS Data Bus onto the OEM bus, and to propagate only pre-authorized vehicle information onto the ITS Data bus. In some cases, encryption and authentication may be required. The actual implementation may be anything from a full-blown network router to a simple shared memory arbitrator.

ITS Data Bus - Since it is impractical to attempt to get all automobile manufacturers to adopt a single multiplex bus for all their vehicle systems, and to allow the retrofit of electronics to the vehicle after it is shipped, the ITS Data Bus is designed to allow multiple devices from different vendors to be connected to the vehicle systems via the gateway controller. The ITS Data Bus is a self-configuring, peer-to-peer, multi-drop network supporting a 115 Kbps data rate. Existing specifications such as the emerging SAE CAN Task Force specification (a 500 Kbps unshielded twisted pair implementation) were considered by the Committee, but none were found to meet the requirements developed by the IDB Committee.

Accommodated Devices - These include all types of electronic devices that might be connected to the vehicle, including pagers, cellular phones, RF tags, navigation computers, and GPS receivers. The degree to which these devices can interact with the vehicle system is controlled by the Gateway Controller. Since much of the ITS Data Bus traffic is between devices (rather than between the ITS Bus and the OEM Bus), accommodated devices must be able to interact with each other without any intervention by or support from the gateway controller, and, in fact, even in the absence of a gateway controller. However, in the absence of a gateway controller, the devices will not be able to access any vehicle data or functions. Such a self-contained IDB may be appropriate for some applications, but not for many others.

INTERFACES AND PROTOCOLS

This section describes the various interfaces and protocols that are required for the IDB to function properly in a vehicle with devices docked on the bus. These interfaces are depicted in both Figure 1 and Figure 2.

The vehicle-to-gateway interface, which is implemented by the auto manufacturer, defines the connection between the vehicle bus and the gateway controller. If the gateway controller is a logical function provided by another module (e.g., an OEM navigation system with a CPU), this interface may be simply an API (Application Programming Interface). If the gateway is a separate physical device or a physical component in a device (such as a radio with a gateway added), then the interface will specify the physical and other appropriate layers of the protocol stack. This interface will also specify the DC power requirements and may also provide access to an analog audio bus so that accommodated devices such as navigation systems can provide their audio output through the vehicle's stereo speakers. Specific details of the vehicle-to-gateway interface are provided by the vehicle manufacturer, and are proprietary to that manufacturer.

The gateway-to-accommodated devices interface specifies how data is to be presented to the gateway controller so that the data can be read by the vehicle systems, and how vehicle data is to be retrieved from the gateway controller for use by the accommodated devices. An auto manufacturer may choose to implement special codes in the gateway that would allow it to access vehicle parameters over a wireless communications device attached to the Bus. Therefore, this interface must provide appropriate security and authentication services to ensure that the vehicle systems are not compromised. This feature is vital to provide adequate liability, safety, and warranty coverage for the automobile manufacturers.

(Insert figure 2 about here)

The device-to-device interface defines how accommodated devices communicate with each other over the ITS Data Bus, and includes the complete ITS Data Bus protocol, which is based on the International Standards Organization's Open System Interconnectivity (OSI) standard (8). This standard contains a specification for a seven-layer protocol stack, only three of which are being implemented for the IDB. The development of the SAE ITS Data Bus Standard comprises three standards documents, based on the three layers of the OSI protocol being implemented: J2366/1 Physical Layer (3); J2366/2 Data-link Layer (4); and J2366/7 Application Layer (5). These layers are depicted in the lower portion of Figure 2, with the lowest-numbered layer on the bottom of the stack. Messages passed between and among the various accommodated devices and the gateway consist of a header followed by a message body which can contain up to 65KB of data. This interface includes the facility for private messages, so that a device manufacturer can implement special or custom functions among its own devices to gain competitive advantage. This capability is provided for by the capacity to use embedded protocols, such that any protocol can be encapsulated entirely inside the IDB message, and then be "unpacked" and used by the receiving device. In addition, since it is unlikely that an Information Service Provider will be able to offer all the services desired by drivers and passengers, future access to the Internet will be required from inside the vehicle via wireless communications devices connected to the ITS Data Bus. This protocol provides the flexibility to accommodate such a variety of functionalities.

Additional SAE standards documents are being developed for the gateway (6), and for a IDB conformity test (7). These efforts are just in the beginning stages at the time of this writing.

AN EVALUATION PLATFORM FOR THE IDB CONFORMITY TEST

Previous work (9, 10) has described the development of functional requirements and system concepts for an In-Vehicle Information System (IVIS) which offers a radically different approach to providing drivers with the ITS information they need to complete their journeys in a safe, orderly, and expeditious manner. Currently, drivers visually gather this information, mostly from sources beyond their windshield (e.g., signs and roadway markings), and partly from information displays inside the vehicle (such as the speedometer and fuel gauge). As noted above, aftermarket systems are becoming available which can be added to vehicles to aid in travel and/or the conduct of business in the vehicle.

The IVIS serves as the interface between the driver and the driving information environment. The IDB permits installation of multiple devices, each with its own driver interface, which can increase the likelihood of driver distraction and thus the risk of an accident. The goal of the IVIS project is the development of a fully-integrated IVIS which will filter, prioritize, enhance and display highway and vehicle information safely and efficiently, while also providing an integrated driver interface to a variety of ATIS information sources. Such a system, using modern digital technology, tailors information both to the driver's needs and to the driving environment. IVIS must perform three high level functions (10). It must 1) interact with accommodated devices, 2) manage information, and 3) interact with the driver. To develop and evaluate an IVIS prototype without creating hazards on the road, a laboratory platform has been devised which permits testing in a laboratory (off-road) setting. The development and testing of an IVIS is based on a computer network which has been built. This LAN emulates the functioning of various devices which send information to a PC serving as the IVIS, the device on which the information management logic is developed and tested. In addition to the IVIS development work, this platform is also being used to evaluate various components of the IDB standards. For example, messages are being passed through the LAN using the IDB message header standard, thus demonstrating that the various fields proposed for the IDB header are adequate.

IVIS SYSTEM CONCEPT AND DESIGN

Because the IVIS must be capable of accommodating a variety of ATIS subsystems, as well as a variety of driver and mission needs and preferences, the system must be flexible and easy to use. There is obviously a wide range of decisions to be made in the design of a system such as the IVIS, in terms of how much impact the decision has on driver use -- some decisions have no impact beyond whether the system functions or fails, whereas others, such as how many messages to display at one time, directly impact driver use. In between these two extremes, however, are decisions which may impact driver use in ways which are not immediately apparent, and these are the ones which contribute to a highly successful system when they are properly considered and decided upon during system design and prototyping, rather than as an afterthought.

(Insert figure 3 about here)

The In-Vehicle Information System

An IVIS reference model is presented in Figure 3, which depicts the various components of an ITS-equipped vehicle with which an IVIS must contend. A full description of the functioning of the IVIS module in Figure 3 is presented in (9). Briefly, the IVIS must perform three high level functions (10). It must interact with devices (part A of Figure 3), manage information (part B1 and B2 in Figure 3), and interact with the driver (part C). The "gateway" in section A2 of Figure 3, described previously, serves the same functions here as described for the previous figures. In order to communicate with each other, the IVIS and the driver, devices are connected to the IDB. In the arrangement shown, communication between the vehicle and the infrastructure is performed by the various accommodated devices, each with its own communication path, as detailed in the National Architecture. The devices, in turn, do whatever information processing they are designed to do, and then send the prepared information to the IVIS to be presented to the driver. As discussed previously, the various devices can also communicate with each other on the IDB. For example, the yellow pages subsystem would need to tell the N&RG subsystem where a particular business is located, so that the N&RG subsystem can direct the driver to that location. In addition to the information management and presentation functions, the IVIS also provides the input mechanism between the driver and the various subsystems. Such input might consist of the intended route for the N&RG subsystem or the desired phone number for the cell phone. This input is received by the IVIS from the driver and routed to the appropriate subsystem.

(Insert figure 4 about here)

IVIS DEVELOPMENT AND IDB TESTING EFFORTS

The system development platform comprises a number of personal computers, both high- and low-end, linked via an ethernet LAN, with a high-end PC serving as the IVIS computer. This platform is shown in Figure 4, in which the various components are appropriately labeled. In this figure, actual devices are shown in place of the original PC which emulated them, as a later stage of development and evaluation. The scenario generator provides the network with a simulated trip, either a sequence of events and timing from an actual trip, or a fictitious trip which produces the types of situations needed to test the functioning of the logic and display routines of the IVIS. The other PCs and actual hardware units in the LAN provide the functions of various accommodated devices, as indicated in the illustration. In its simplest operation, the development platform is driven by the signals broadcast to the LAN by the scenario generator, which provides the event signals for a trip. These signals are received by the other PCs or devices in the LAN, which then perform their appropriate functions by sending messages into the LAN. These messages are, in turn, collected by the IVIS PC and processed for display, performing the information management functions described above. Because these messages are encoded in the IDB standard, this platform provides an initial evaluation system for the developing SAE standards. As the coding is completed, other aspects of the SAE family of standards for the IDB receive a preliminary evaluation for adequacy and functionality in this platform.

The IDB Conformity Test (7) will be used to certify that devices which are to be installed on the IDB meet the minimum IDB requirements. Such certification tests are routinely conducted by recognized organizations such as the Underwriter's Laboratory. The IDB conformity test would be conducted to assure that devices so labeled would perform within the parameters of message handling, fault detection and tolerance, and power consumption prescribed by the IDB standard. Devices so labeled can be purchased and installed by consumers with confidence that the performance of those devices will be as described in IDB and device literature. The first step in such a process is, of course, to design and evaluate the conformity test. The IVIS Development Platform is an ideal setting for such development, since it is already programmed to function according to the ITS Data Bus protocols and standards. As such, the platform is a ready environment for assessing both the test and the test's ability to evaluate potential accommodated devices, since these devices can be inserted into the LAN which comprises the IVIS Platform.

CONCLUSIONS

The availability of increasing numbers and types of advanced automotive electronic devices, together with the ITS services which provide them with the information needed to permit them to function, assures that these devices will be installed in more and more vehicles. Due to the increased complexity of these devices, installation will be much more complex than in the past, requiring as it will connection to vehicle information sources in addition to DC power. Installation of several of these devices creates the possibility that several of them will signal the driver nearly simultaneously, thereby distracting rather than aiding the driver. Solutions to both the complexity of installation and use were presented. The ITS Data Bus provides for a certifiably safe, inexpensive and easy installation process, while an In-Vehicle Information System helps to manage the larger amounts of information and the driver-system interface. These solutions serve to enhance the safety of road travel, as well as efficiency and user satisfaction in an increasingly complex transportation system.

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FIGURES

figure 1:

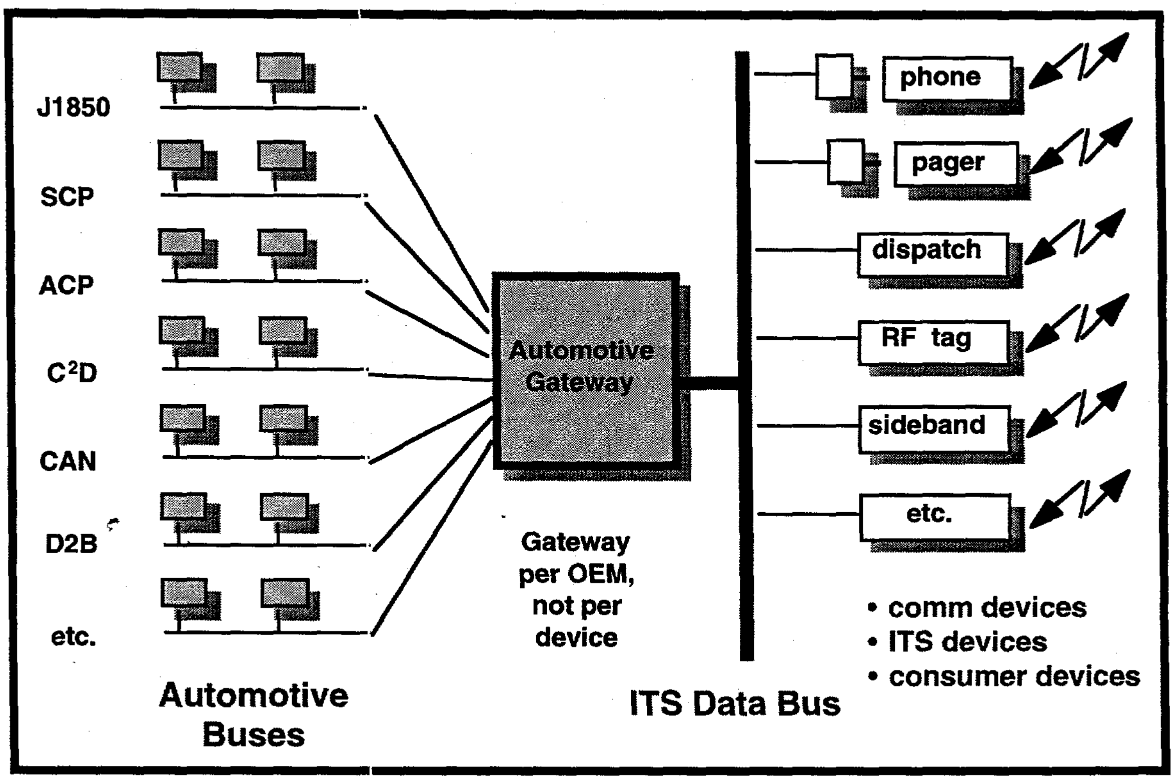


figure 2:

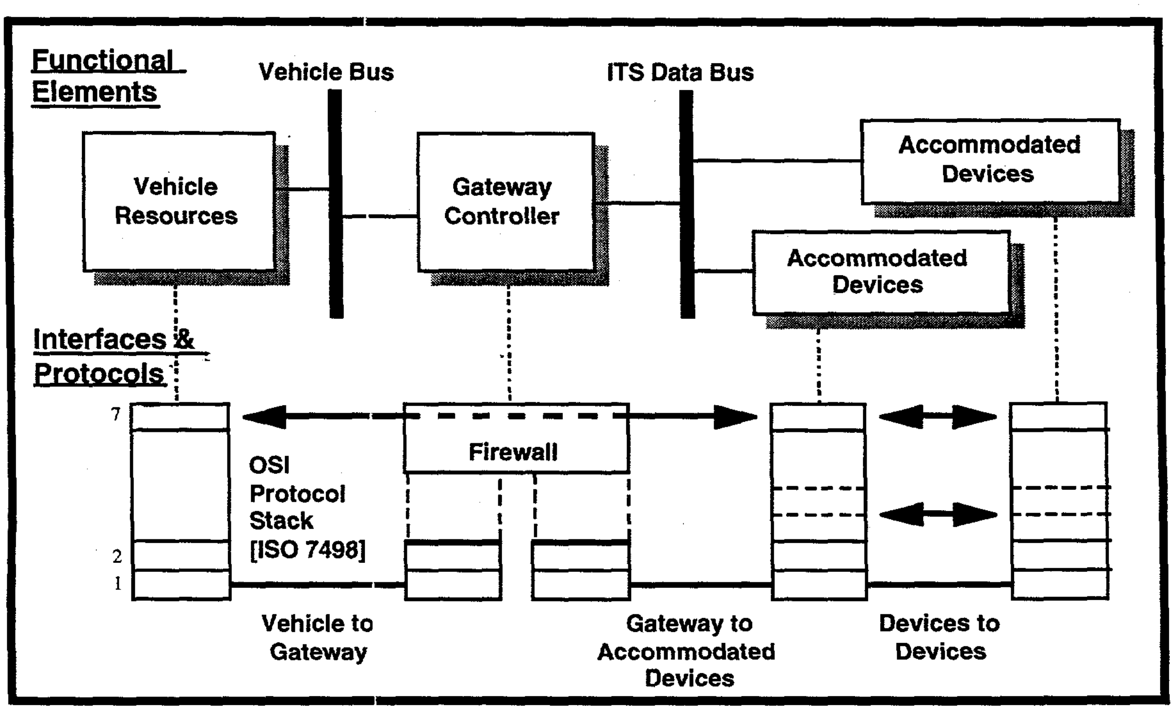


figure 3:

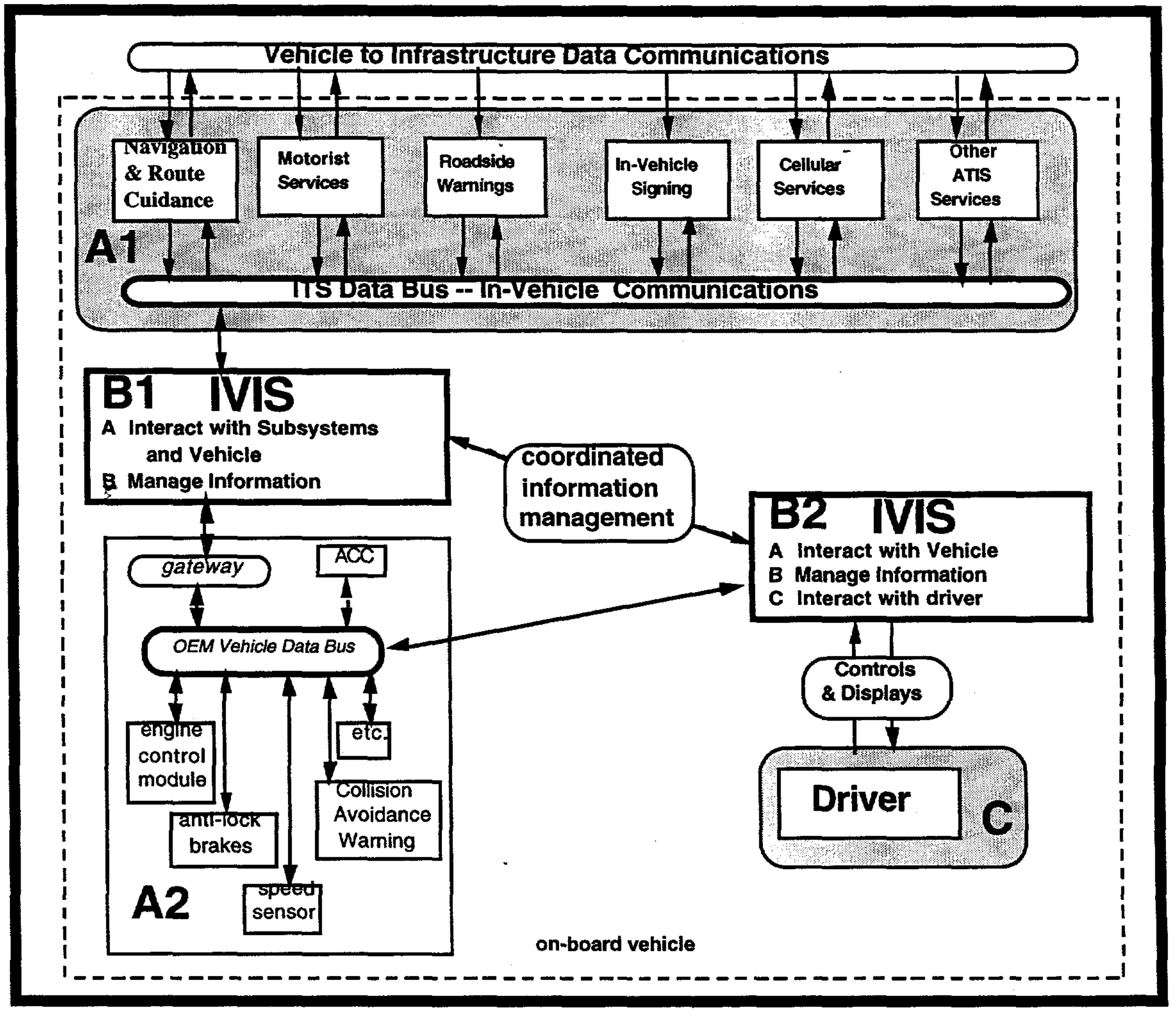
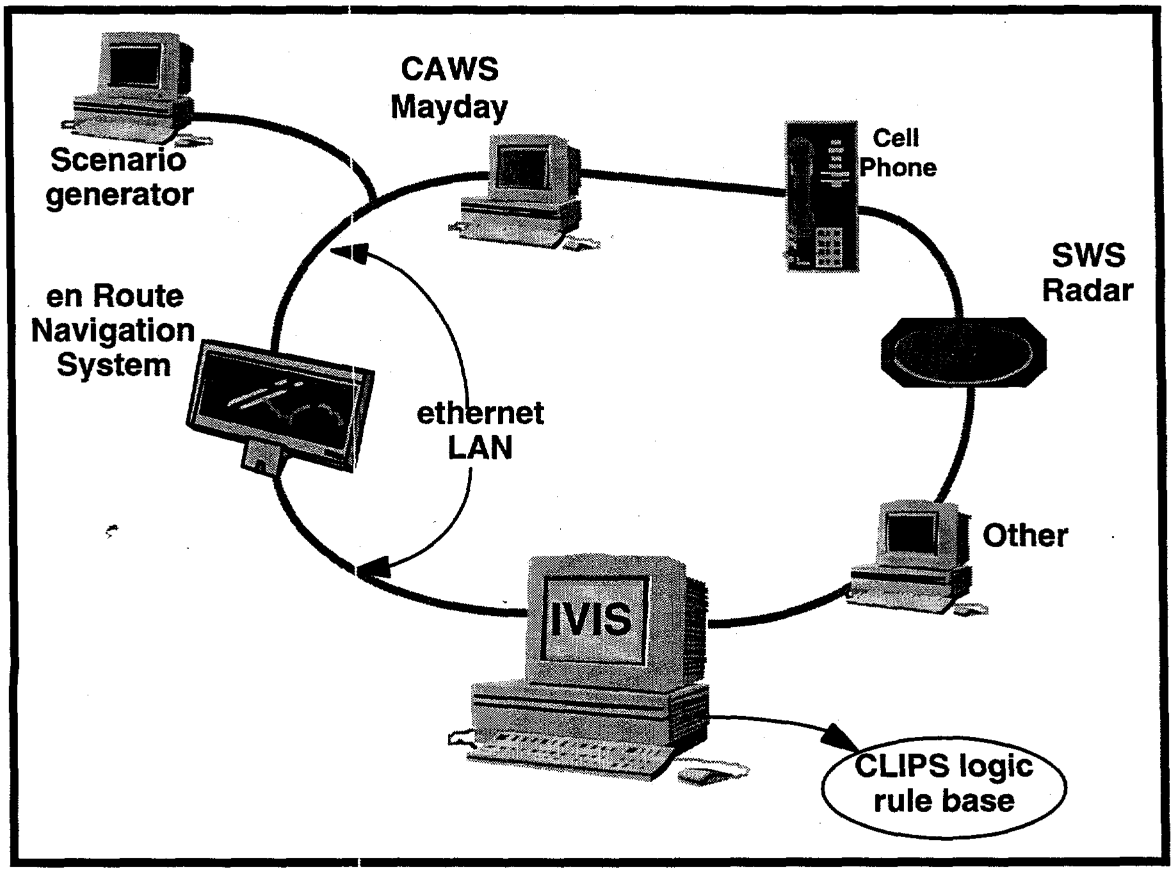

Vehicle to Infrastructure Data Communications
Navigation & Route Cuidance
Motorist Services
Roadside Warnings
In-Vehicle Signing
Cellular Services
Other ATIS Services
A1
ITS Data Bus -- In-Vehicle Communications
B1 IVIS
A Interact with Subsystems and Vehicle
B Manage Information
coordinated information management
B2 IVIS
A Interact with Vehicle
B Manage Information
C Interact with driver
gateway
ACC
OEM Vehicle Data Bus
engine control module
etc.
anti-lock brakes
Collision Avoidance Warning
speed sensor
A2
Controls & Displays
Driver
C
on-board vehicle

figure4:


CAWS
Mayday
Scenario
generator
Cell
Phone
SWS
Radar
en Route
Navigation
System
ethernet
LAN
Other
IVIS
CLIPS logic
rule base

FIGURECAPTIONS

Figure 1 - Dual Bus architecture, showing samples of OEM multiplex data buses, the proposed gateway, and the proposed IDB.

Figure 2 - IDB architecture reference model, showing the functional elements in the top portion and the interfaces and protocols (based on the ISO seven-layer model) in the lower level. -

Figure 3. A distributed IVIS, showing the various interfaces required. The "In-Vehicle Data Communications" function is handled by the ITS Data Bus.

Figure 4. The IVIS Development Platform and its Local Area Network (LAN). This illustration shows several physical devices substituted for the respective PCs.