Issues in Communication Standardization for Advanced Vehicle Control Systems

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Several issues must be addressed when establishing intelligent vehicle-highway system (IVHS) communication standards, particularly for the most advanced of these systems, the advanced vehicle control system (AVCS). Each of the three stages of AVCS evolution have separate issues that must be addressed in order to define communication standards. It is recommended that measured progress toward the development of IVHS communication standards be based on a solid foundation so that they do not risk becoming impediments to progress. Given the current state of development of IVHS technology, more questions are raised than are answered.

The intelligent vehicle-highway system (IVHS) is an assortment of communication, computer, sensing, and control technologies that can be applied to observe, guide, or control the movement of vehicles in a traffic system. IVHS requires the operation of vehicles and roadways as a combined system rather than as separate entities. This requirement raises important issues about the information that must reside with each element of the complete system (individual vehicles, individual locations along the roadway, and a central wayside location) and that must be communicated from element to element. The complexity of the road transportation system and the mixture of public and private sector interests virtually mandate that IVHS development and implementation will involve many different organizations. In order for these separate organizations to develop their respective portions of a combined system, standards must be established to govern the interfaces among those portions, particularly those involving the exchange of information.

Several communication standardization issues must be considered to meet the needs of the advanced vehicle control system (AVCS), the most advanced of the IVHS technologies under active consideration. These issues are being raised now so that the IVHS standards that are developed to meet relatively near-term needs will have sufficient flexibility and growth potential to meet the longer-term needs of AVCS.

IVHS developers must thoroughly understand the relative merits of diverse technical approaches and the inherent limitations of alternative technologies before applying the constraints inherent in standardization. If standards are imposed before this level of technical maturity is reached, the risk is high that the most promising solutions will be precluded by the standards, and the technology could be "dead ended." Of course, the costs of such a mistake would not become apparent until some years after the standards were imposed. At that time, either activity in the application field would decrease or all participants would be forced to undergo a costly and time-consuming retrenchment, in effect discarding their previous work and starting over under a new set of standards with a greater growth potential. Judicious timing of the decision to standardize can avoid such problems.

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INFORMATION NEEDS OF AVCS

All IVHS applications depend on timely availability of information, which must be supplied from one vehicle to another, from the roadway to the vehicle, or from the vehicle to the roadway. Definition of *communication* needs must follow definition of the *information* that must be supplied from one system element to another. That information may be transferred by means other than communication, such as direct sensing, so it is important to define the most appropriate means for transferring each category of information.

The communication needs of AVCS differ from the communication needs of the other IVHS functions in one fundamental way. Because virtually all AVCS communication is safety-critical, an AVCS communication failure would be likely to produce an accident with significant potential for property damage and injury. Therefore, AVCS communication links must incorporate redundancy in any of several forms (e.g., parallel communication links, multiple transmissions of data, or encoding schemes). The phenomena that AVCS systems address (vehicle dynamics) occur on time scales of fractions of a second; in contrast, phenomena that the other IVHS functions address are more likely to occur on scales of multiple seconds or minutes. Therefore, AVCS information changes more rapidly and, in turn, updates must be communicated more frequently. On the other hand, the quantity of information that must be communicated for each update may be substantially less than for the advanced traveler information system (ATIS), for example.

Because AVCS is not a single system, but rather a group of technologies, it has been subdivided into relatively homogeneous subfunctions. Mobility 2000 defined three levels of AVCS functionality: AVCS I, II, and III. The requirements of these subfunctions are cumulative rather than distinct, so that AVCS III incorporates all of the requirements of the two lower levels. AVCS I technology enhances the safety of a driver's responses to the road environment by offering perceptual enhancements, warnings, and control or stability augmentation. AVCS II adds the capability for vehicles to operate under automatic lateral and longitudinal control on individual links in a network, to enhance both safety and link capacity. AVCS III extends these capabilities to comprehensive networks on freeways, so that vehicles can operate under full automatic control from the freeway entrance ramp to the exit ramp. Communication issues relevant to each of these three levels of AVCS operation must be addressed in the development of IVHS communications standards.

COMMUNICATION ISSUES RELEVANT TO AVCS I

Virtually all AVCS I functions are centered in the individual vehicles and can be applied anywhere in the road system, including freeways, rural roads, arterials, and local streets, without requiring infrastructure modifications. At early stages in the evolution of AVCS I, relatively few vehicles will be equipped with AVCS I technology. Therefore, encounters between vehicles will usually involve only the direct sensing of unequipped vehicles by equipped vehicles. As the AVCS I market penetration grows, the potential for interactions between equipped vehicles will increase and communication between those vehicles will become more of an issue.

The communication links relevant to AVCS I appear to be almost entirely vehicle-to-vehicle. Communications between vehicles and the roadway that could support the AVCS I warning functions could be incorporated within the longer time-scale functionality of ATIS or ATMS. These communications would be broadcast warnings of accidents or incidents ahead so that drivers could slow down or adjust their routes. Existing freeway traffic management systems communicate this information to drivers using changeable message signs, for example.

The information communicated from one vehicle to another in an AVCS I system would generally be a warning of a potentially unsafe condition, such as

- Watch out, I'm in your blind spot!
- I'm going to change lanes in front of you.
- I've just had a flat tire (or some other failure).
- I've just slammed on my brakes!

The information content of these messages is not large. Codes could be used to indicate the specific condition, identify the vehicle sending the message, and provide enough information (lane, direction, and milepost location) for the other vehicles to locate the transmitting vehicle. Although the message would be of very limited length (just a few bytes), it would have to be provided rapidly (perhaps within 100 ms), and with priority over other, less safety-critical information. The message would also have to be provided repeatedly within a short time so that if the first transmission fails, subsequent transmissions would have a high probability of success. The number and frequency of repetitions that would be needed to ensure adequate safety cannot be specified without substantial analysis and testing.

Numerous issues must be considered in defining the communication standards that would have to be applied even for this relatively simple case, including message length, repetition rate, range, selectivity, and reliability. Clearly, such issues require analysis, design, and testing. It is difficult to see how communication standards could be defined intelligently without resolving these issues.

COMMUNICATION ISSUES RELEVANT TO AVCS II

The extension to AVCS II functionality significantly increases the communication requirements. Two additional types of vehicle-to-vehicle communication are likely to be needed, as well as communication between the vehicle and the wayside computer systems. The AVCS II function assumes that suitably equipped vehicles would be operated in platoons on suitably equipped facilities, with very close longitudinal spacings between vehicles within the platoons. This close-formation operation would require rapid communication of information between the vehicles within a platoon in order to ensure stable platoon dynamics. Additional vehicle-to-vehicle communications would be needed to enable vehicles to safely enter and leave platoons.

Research on platoon dynamics indicates that each vehicle in a platoon would need continuing and timely information about the movements of its predecessor and the platoon leader (with updates perhaps as frequently as every 20 ms). Safe operation of platoons would also require that warnings of emergency conditions be "immediately" communicated from the failed vehicle to all the other vehicles in the platoon. Because of the very close spacings between vehicles in platoons (about 1 m), this requirement is likely to be more stringent in terms of response speed and reliability than for the analogous function in AVCS I. However, research has not yet been done to define how fast is fast enough.

Merging of vehicles into moving platoons and separation of vehicles from platoons introduce additional vehicle-to-vehicle communication needs. The quantity of information required for these purposes is not large compared to that required for the longitudinal control within the platoons, but the information generally comes from further away and from a direction where there is significant potential for interference and loss of line of sight (adjacent lane, substantially ahead of or behind the receiving vehicle).

The communications between vehicle and wayside for AVCS II introduce an element not present in AVCS I. These communications, primarily one-to-many communications of command information from the wayside to the vehicles, are generally meant to apply locally rather than globally. Therefore, wide-area broadcasting would not be an appropriate medium for this information, and a more selective medium would be needed. Many-to-one communication of information from the individual vehicles to the wayside control computers may also be needed. The amount of information to be received from each vehicle is not large, but the number of vehicles could be very large in a major metropolitan region.

It may be more appropriate to communicate the warnings about vehicle problems directly from vehicle to vehicle, without involving the wayside. Hopefully, the system may operate without requiring each vehicle to communicate its state information to the wayside on a regular basis. It may be adequate for the wayside system to know each vehicle's position at relatively infrequent intervals (several seconds or even minutes), or it may not even be necessary for the wayside system to know any more than aggregate vehicle flow information. Considerable system engineering analysis and simulation is needed to establish the necessity of communicating each of these types of information from each vehicle to the wayside.

The types of general issues that need to be addressed to understand AVCS II communication needs include tradeoffs between sensing and communication, needed repetition rates for different messages, relative roles for vehicle-to-vehicle and vehicle-wayside communications, assignment of multiple priority levels to different messages, and spacings between wayside communication devices.

COMMUNICATION ISSUES RELEVANT TO AVCS III

The communication needs of AVCS III operations will include all of those for AVCS I and II, an additional set of vehicle-wayside communications associated with the system management functions of AVCS III, and a new element of wayside communications between distributed and central computing facilities. These new communication needs do not have the strong safety implications of their predecessors, but are in a sense more related to ATIS communications.

The new messages for AVCS III are all one-to-one communications of limited amounts of information. Individually each message would not impose a significant communication burden. However, in a large metropolitan system (e.g., Los Angeles), the number of vehicles involved could make this a very large communication burden. This factor leads to the consideration of highly distributed wayside control computers, each of which would have to communicate with only a limited number of vehicles. There would then be a significant amount of communication among these wayside computers and between each of them and the central coordinating computers. The system design implications of different configurations for these computer and communication systems are extremely complicated and have not yet been addressed at even the most rudimentary level. The appropriate distribution of wayside and vehicle control functionality, the depth of hierarchy in the system structure, and the implications for both computational and communication burdens will be understood only through substantial system engineering effort.

These questions address the central issues in system-level design and system management for an automated freeway system. These are probably the most technically difficult questions in the IVHS field, and will therefore require years of research to answer. Unfortunately, the range of possible answers, viewed at this stage in IVHS development, is so broad that it does not appear reasonable even to define order of magnitude bounds on the ensuing communication needs.

DIRECTION OF IVHS COMMUNICATION STANDARDS

Given the current state of development of the various IVHS technologies, what can be done now to move toward standardization of IVHS communications? It is clearly in the interest of the vendors of any of the IVHS components or systems to have standards developed as rapidly as possible to simplify product development and marketing tasks. On the other hand, so little is understood about the large-scale system implication of *any* of the IVHS technologies that it appears to be premature to define comprehensive communication standards at this time.

The pressure for standardization is not likely to relax in the face of these shortcomings in current knowledge, and indeed standardization should not have to wait until *all* technical uncertainties are resolved. The interesting challenge then is to try to develop standards frameworks with sufficient flexibility and growth potential to accommodate all reasonable future needs. It would be the height of folly to get locked into a set of IVHS standards that could meet the needs of IVHS applications only 5 or 10 years, rather than considering from the start the long-term evolutionary potential of IVHS and making sure that potential is not artificially constrained by insufficiently progressive standards.

It may be possible to embark on the road toward IVHS communication standardization once there is basic agreement about the choice of physical medium (e.g., radio, optics), the general network topology, and rough estimates of data traffic. At that point, it may be possible to address standardization of packet and frame formats (addressing conventions, error-correction and detection capabilities), media access protocols, and some higher-level protocols (such as routing). However, we are not yet even close to determining the underlying issues, such as the physical medium and network topology that would be most appropriate for any of the IVHS functions.

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