VEHICLE ALERT SYSTEM

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ABSTRACT

The Vehicle Alert System (VAS) project focuses on cooperative alert services based on timely and reliable communication under the challenging circumstances pertaining to a highly mobile vehicular network. Through a cross-layer design, we gain the flexibility needed to adapt the system to the individual requirements of three chosen application scenarios that represent different situations where cooperation between vehicles can make a significant impact. The VAS project is a collaboration involving academic as well as industrial partners and the final stage of the project is a demonstrator that implements results from the research.

INTRODUCTION

Vehicle Alert System (1) is a project concerning the areas of cooperating embedded systems, vehicular ad-hoc networks, wireless sensor networks and wireless digital communication. VAS is associated with the research profile Centre for Research on Embedded Systems (CERES) at Halmstad University in Sweden. Research within the VAS project is performed through collaboration between Halmstad University and industry, where the industrial partners are Volvo Technology Corporation (VTEC), Free2Move, and SP Technical Research Institute of Sweden.

There exists a plethora of vehicle safety and comfort application projects around the world, whereas only a handful is mentioned here. The EU project Cooperative Vehicle Infrastructure Systems (CVIS) (3) focuses on enabling a wide range of cooperative services based mainly on vehicle-to-infrastructure communication and it will make use of the CALM framework as a communication technology enabler. Another European project with focus on safety applications is the Safespot project (4). Vehicle Infrastructure Integration (VII) (5) is an American initiative launched in 2003 that primarily focuses on congestion relief and crash prevention by using the upcoming American DSRC standard WAVE.

A communication system, wireless or wired, has some sort of communication stack containing rules on how the actual communication should take place. These rules are encapsulated in protocols and can be organized into different layers stacked above each other. The VAS project is inspired by the OSI communication model (2) but focuses mainly on four layers. To provide deterministic access to the unpredictable wireless channel and to use different error control strategies, the *physical* and the *data link layers* are included. To be able to handle an end-to-end addressing scheme, fast handover and routing, a *network layer* is needed. Finally, an *application layer* that interfaces the actual safety application completes our protocol stack. The VAS project is a unique research project in the sense that it includes research on four different layers with special focus on optimizing the different levels separately as well as jointly. This is done in order to increase the probability of timely packet delivery as well as to increase the reliability of the system. Compared to traditional wireless systems with static or nomadic nodes, a vehicle communication system is characterized by its highly mobile and dynamic nature where relative velocities can reach hundreds of kilometres per hour. This imposes new requirements on all layers of the system and three different application scenarios have been identified to highlight interesting research questions with respect to vehicular communication systems. This paper describes the application scenarios chosen for VAS and the cross-layer approach taken in the project, i.e. investigating how the application scenario requirements influence various parts of the protocol stack. The main question concerns how information, residing in each layer, can be used to create a robust and deterministic alert system even under difficult conditions, such as high vehicle density and time critical communication.

APPLICATION SCENARIOS

Within the VAS project three application scenarios based on v*ehicle-to-vehicle (V2V)*, v*ehicle-to-infrastructure (V2I)* communication and a combination thereof have been chosen to highlight properties that are desirable in the field of vehicular networks. The most important properties targeted are *scalability*, *dependability* and *real-time capabilities*. The goal is to combine these properties with the desire to enable communication over *varying distances* even under the circumstances of *high mobility* and varying *traffic density*. Each of the chosen application scenarios represents different aspects of a vehicle alert system such as varying velocities, network topologies and requirements on context awareness. The application scenarios are “emergency vehicle routing”, “merge assistance” and “pedestrian crossing warning”. The choice of scenarios is motivated by their ability to highlight the previously mentioned research properties.

KEY PROPERTIES

Dependability is a main requirement of a vehicle alert system since it must be available or it must report the lack of availability. It must also offer correct services reliably at any time and be safe even in the presence of human errors and system failure. The amount of dependability required is influenced by the application at hand. A possible life saving application calls for a higher degree of dependability than a comfort-oriented application. Information need not only to be delivered reliably in terms of contents, it often has strict *timing requirements*. Exchanging information with the goal to prevent road accidents puts hard and tight deadline requirements on the communication system. If such a message, that is delivered correctly, fails to make its deadline it is of no value.

Traffic density depends on the time of day, the type of road (urban, urban highway, rural highway etc.). For low traffic density, the number of vehicles that have to receive a warning or recommendation and that take part in the communication process is low. This may make information management and timing requirements easier to cope with. On the other hand, if information has to be relayed via intermediate nodes, the lack of sufficient communication nodes might keep important data from reaching its proper destination. Traffic density is closely related to the concept of *scalability*. New nodes must be accommodated into the network while others should be able to leave without major impact on the system's overall performance. In the early stages of the introduction of a VAS-like system, only a limited number of vehicles will be equipped with the communication technology necessary for becoming a valid part of the network. The system must scale fast enough to cope with long term changes in the percentage of equipped nodes and with short term changes, e.g. from an almost empty highway to a sudden traffic jam. Alerting all vehicles in immediate vicinity through short-range communication is vital in most applications. Nevertheless, in some cases longer communication distances need to be covered. Both roadside infrastructure with a larger communication range and multi-hop communication involving intermediate vehicles can be appropriate solutions to the problem.

The *high mobility* of a vehicular network makes both the establishment and maintenance of communication paths more difficult. Information exchange at relative velocities of several hundred kilometres per hour is challenging and sets a vehicular ad hoc network apart from traditional mobile ad hoc networks. Additionally, timing requirements are influenced by the high velocities which require short reaction times from both system and driver in order to prevent accidents.

EMERGENCY VEHICLE ROUTING

In the emergency vehicle routing scenario, Figure 1a, vehicles warn each other about approaching emergency vehicles, e.g. ambulances, and inform drivers so that a path can be cleared in a timely and coordinated way. This information can be sent out seconds or even minutes in advance based on both the actual traffic situation and the emergency vehicle's planned route. Additionally, the emergency vehicle should be able to communicate with VAS infrastructure to query for suitable routes to its destination, as well as to request traffic signal pre-emption. Rescue vehicles traditionally use sirens and light to inform other traffic participants that they are approaching. Using V2V communication, the zone of awareness can be extended considerably.

In this application scenario, V2V communication is crucial as the path of an emergency vehicle is not restricted to certain areas or road types. V2I can be used whenever available to provide additional services like traffic signal pre-emption and for more efficient broadcasting of data. Dependability is of utter importance since lacking or contradictory information can lead to accidents and traffic chaos that hinders the emergency vehicle from passing through, risking human life. Both scalability and mobility are keywords in this type of scenario since the number of participating nodes and their mobility patterns are strongly and dynamically varying parameters in the system. Warnings and recommendations must be given before a specific deadline which in its turn could be quite generous.

MERGE ASSISTANCE

The merge assistance scenario, Figure 1b, illustrates how cooperating vehicles can increase safety and efficiency at highway on-ramps. Potentially hazardous situations include those where the speed difference is high, where on-ramps are short, and where vehicles have limited maneuverability, e.g. trucks. These types of vehicles have higher demands on cooperative behavior due to lower acceleration capability and greater vehicle length. Vehicles that negotiate with each other could advise drivers on speed and acceleration, solving hazardous situations before they arise. A highway entrance might be a given spot for roadside infrastructure. A roadside unit can help relay data between vehicles involved in the merge situation as well as spread other type of information (e.g. road condition data) to passing vehicles.

The communication needs related to the handling of conflicts in a merge scenario can be solved by V2V or V2I techniques or a combination of both. If the merge assistance scenario is to be translated to a more general lane change warning scenario, the importance of V2V becomes evident. Timing requirements are high as many nodes need to negotiate (i.e. communicate) with each other within a limited time frame. Warnings and recommendations that are given past the deadline are not only useless but dangerous. Scalability and high mobility are of medium interest as both an approximate maximum relative velocity and maximum number of participating nodes can be estimated in advance.

PEDESTRIAN CROSSING WARNING

Accidents at crosswalks, between pedestrians and vehicles, often result in serious injuries even at relatively low speeds. The pedestrian crossing warning scenario, Figure 1c, employs mainly V2I communication to warn the driver that pedestrians are located on, or near the crossing. Crosswalk signaling infrastructure can also benefit from interaction with vehicles. If a vehicle is unable to stop in time, for example due to road conditions or driver inattention, the crosswalk signaling system could delay giving the "walk" signal or alert pedestrians. At unguarded crossings detectors could alert drivers that there are pedestrians waiting to cross.

This scenario is mainly based on V2I communication with a dedicated roadside unit near accident-prone pedestrian crossings. The number of communicating nodes as well as their speed is low, giving scalability and high mobility low priority in this scenario. The real-time issue, on the other hand, is of great importance as decisions need to be made within a hard and tight deadline to prevent potentially fatal accidents. Due to the same reason, the dependability of the system must be high.

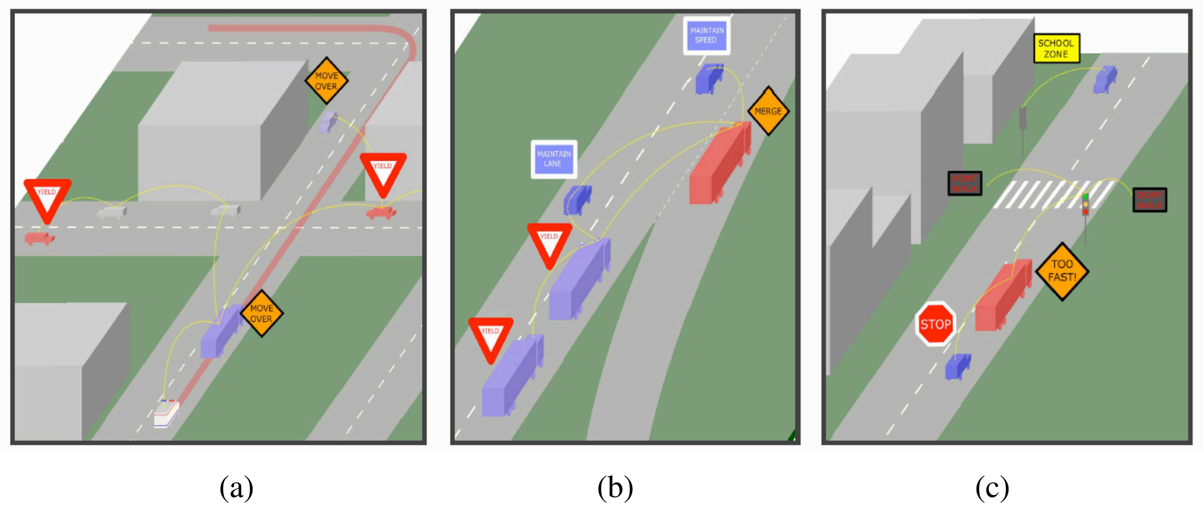

Figure 1. The application scenarios; (a) Emergency vehicle routing, (b) Merge assistance and (c) Pedestrian crossing warning.

REFERENCE ARCHITECTURE AND TERMINOLOGY

The VAS system is based on autonomous information dissemination, analysis and decision making performed mainly by in-vehicle software agents supported by centralized and roadside services accessed via V2V and V2I communication technology. Functionality within the VAS system is realized through cooperation between members of two principal subsystem categories, *mobile nodes* and *stationary nodes*, hereafter referred to collectively as just nodes. Mobile nodes are associated mainly to vehicles while stationary nodes are associated many-to-one to the infrastructure. Stationary nodes can be separated further by considering their operational zone; *roadside stationary nodes* are placed along roads and are concerned with the immediate surroundings while *centralized stationary nodes* handle information from several sources spread over a large area. Relations between nodes are defined as *interfaces* through which *communication* takes place; these include wired as well as wireless communication paths.

A*pplications* contain the functionality needed for supporting the previously described application scenarios. Within a node, one or several concurrent applications run in a standardized application management framework. At the application level the VAS project combines signal conditioning and fusion algorithms with time and event logic reasoning to construct alert applications.

Nodes receive and transmit context-related information, such as the location of other vehicles, from and to other nodes. All mobile and stationary nodes are peers. Communication uses short-range wireless radio technology through the V2V and V2I interfaces.

Stationary nodes are placed throughout the road network and act as communication infrastructure, e.g. as connection points between mobile nodes and centralized infrastructure or as relay points for peer-to-peer traffic between mobile nodes. The communication interface between stationary nodes can be either wired or wireless which allows for nodes to be temporarily placed at certain locations, for example at a road construction site. Stationary nodes interact through *predefined networks*, i.e. the network topology is known in advance.

A *network* exists if nodes within it can communicate and may consist of both mobile and stationary nodes. The maximum number of nodes in a network is not limited but the minimum number of nodes is two. Networks are constructed in a *self-organizing ad-hoc* manner, i.e. the topology is not defined in advance. A node not belonging to a network is *isolated* and a mobile node that can only communicate with one or more stationary nodes is *vehicle isolated*. Analogously, a stationary node that can only communicate with one or more mobile nodes is *infrastructure isolated*. With respect to the duration of networks, the different types of isolation can be *temporary* or *permanent*.

VAS RESEARCH PERSPECTIVES

This section will provide more information on the research issues discovered in different parts of the VAS protocol stack, Figure 2, which will be subject to deeper investigation. The focus of VAS, as mentioned earlier, is timely delivery of important messages in the context of the chosen application scenarios. The key properties dependability, real-time capabilities and scalability will be investigated more thoroughly at the different layers as well as jointly in the cross-layer design.

The traditional layered communication protocol approach, where each layer is optimized individually, is often not sufficient to maximize the overall system performance. The VAS project is a unique research project in the sense that it includes research on four layers with special focus on optimizing the different levels separately as well as jointly and the included layers are: *application, network, data link* and *physical*. For example, knowledge about the current state of the wireless channel obtained from the data link/physical layers could be shared with higher layers, whereas quality of service (QoS) demands from the application layer could be shared with and enforced in the lower layers, Figure 2. The VAS project aims at developing a context-driven protocol stack where each layer has a module, the *in-layer mediator*, exposing the different tuning parameters of that layer. These parameters are then used by the *Cross-layer mediator* to determine a suitable profile for each specific application, Figure 2. The application requirements on QoS drive the choice of parameters in different parts of the stack.

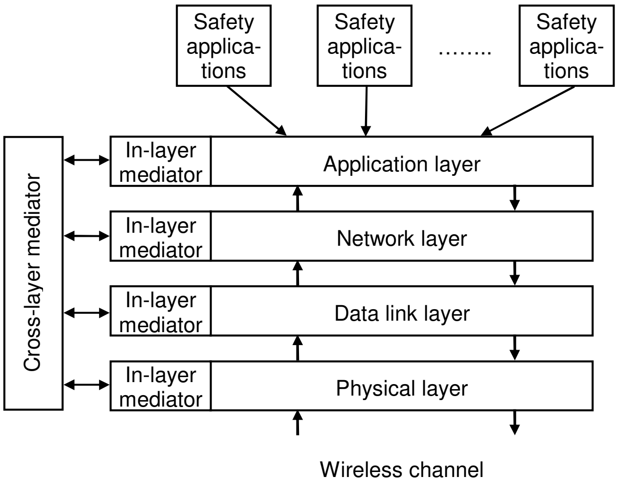

Figure 2. VAS protocol suite addressing cross-layer issues.

The stack handles communication between nodes, which consists of sending and receiving *messages*. A message is characterized by *data content* and *address* where the data content is *application data* or *infrastructure data*. The *Cross-layer mediator* handles optimization using information from layers (called parameter sets, see below) and is not involved in message transfers. Thus the Cross-layer mediator is not a part of the communication stack but act as an adviser for the layers. The properties of each layer and the cross-layer mediator are defined by *parameter sets*. A parameter set consists of *static parameters* and *dynamic parameters*, where the former concerns configuration and the latter status and control information.

APPLICATION LAYER

The application layer provides communication services to the actual applications that are running on the node. Mobile nodes in the VAS system will run multiple concurrent safety-related applications that inform the driver about the state of traffic as well as issue recommendations, see Figure 2. These applications are expected to be produced by a variety of manufacturers and the composition of applications at any point in time is generally not known.

The application layer is responsible for providing applications with access to shared resources as well as basic functionality for modeling and reasoning about the environment. An example of a resource shared between nodes is the wireless medium. An application that cooperatively monitors the wireless medium enables collective adaptation of application behaviour in response to degraded or non-existing communication channels.

The application layer needs to handle data aggregation, control and cooperation in a safe and scalable way which includes managing conflicting application recommendations. To facilitate semantic information exchange between applications and the application layer a *common ontology* needs to be developed (6). Such ontology must be compact and expressive enough to act as a common frame of reference for inter-application as well as inter-node communication and coordination. A time and event logic based reasoning approach has been chosen for defining decision strategies at the application layer supported by observations of the environment received mainly from other nodes. Which observations are most relevant for vehicle alert systems as well as other factors pertaining to observation exchange, such as suitable time-to-live for observation messages and their exchange frequency, will be investigated.

NETWORK LAYER

The purpose of the network layer is to take care of the communication through the network as a whole. Routing data from a source to a destination in a timely and dependable fashion is challenging in a dynamic and unstable topology. A destination in a vehicle alert system is often defined by its geographic position rather than by an individual address (7). Global positioning system (GPS) receivers are playing a vital role for position-based routing strategies. Fast handover between roadside units (within one or between different wireless technologies) at high velocities must be addressed. Predictions based on position, velocity and direction can be used to determine when a vehicle will enter and leave a roadside unit's communication range and handover can be initiated at an early stage. In a scalable system, the number of interacting vehicles is varying greatly. Nevertheless, the wireless medium has to be shared by all communicating nodes. Scheduling traffic of different priority levels (e.g. emergency messages with hard real-time demands vs. entertainment data) is an important aspect that can be addressed on both network and data link layer.

DATA LINK LAYER

The medium access control (MAC) method resides in the data link layer and it decides who will access the channel next. The MAC method is present in all types of networks: wired as well as wireless. MAC protocols can be roughly classified into contention based and conflict-free protocols. Contention based protocols are not suitable for time critical real-time communication since users are not guaranteed a successful transmission within a certain time. Note that successful in this context implies that the transmission is not interfered by any other transmissions in time, frequency, or space. It is thus not related to errors induced by the wireless channel. With contention based protocols a node can experience unbounded delay due to reoccurring collisions. The contention based carrier sense multiple access (CSMA) protocol is the chosen MAC procedure of the upcoming WAVE standard (8) and it is thus not suitable for time critical communications. However, WAVE is the only standard intended for a high mobility vehicular environment that supports V2V and most time critical safety applications with requirements on low delay need to use *ad hoc* V2V communication. In infrastructure based communication via an access point, conflict free protocols (e.g. TDMA, FDMA, CDMA) are more easily deployed since there is a centralized controller in the access point sharing the resources among the nodes. A challenging task is thus to find a conflict-free protocol that works satisfactory in an *ad hoc* V2V communication scenario.

PHYSICAL LAYER

The physical layer deals with the wireless medium, which inherently is very error-prone. To find coding strategies and diversity techniques suitable for the highly dynamic environment that the vehicular network represents is a challenging task. First an appropriate channel model is called for. A channel model is a statistical description of the wireless channel. The development of a channel model starts with a massive measuring campaign, where signals are sent in a real communication environment under realistic conditions and the received signals are measured. All the collected data is then used to construct a statistical model that can be incorporated in computer simulations. Up to date, there is no widely accepted channel model that could be used for developing appropriate channel coding strategies in the high-velocity V2V case.

SUMMARY

The goal of the VAS project is to provide alert application services in a dependable and scalable way based on timely vehicular communication. Solutions for the individual protocol and service layers will be combined in a cross-layer approach to maximize the adaptability to different scenarios. The final stage of the project is a demonstrator that implements results from the research within VAS.

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