The Ex Hoc Infrastructure Framework – Enhancing Traffic Safety through LIfe Warning Systems

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Abstract. New pervasive computing technologies for sensing and communication open up novel possibilities for enhancing traffic safety. We are currently designing and implementing the *Ex Hoc* infrastructure framework for communication among mobile and stationary units including vehicles. The infrastructure will connect sensing devices on vehicles with sensing devices on other vehicles and with stationary communication units placed alongside roads. The current application of Ex Hoc is to enable the collection and dissemination of information on road condition through LIfe Warning Systems (LIWAS) units.

1. Introduction

New 'pervasive computing' technology, i.e., communicating computing technology embedded in everything, has the potential of enhancing traffic safety. The LIfe WArning System (LIWAS)[1] is a traffic warning system based on sensors that are capable of determining whether the surface of the road is dry or is covered with water, snow, or ice. The development of the system, which started in 2003, takes place in a joint research and development project involving University of Aarhus and the LIWAS company. The status as presented in this paper is the status of this project.

Until now the development has primarily focused on the underlying sensor technology of the LIWAS system. A LIWAS sensor is based on among others measuring the reflection from light sources when light is projected on the surface of the road. A vehicle equipped with a LIWAS sensor is able to inform the driver about the state of the road being passed. This can help the driver take precautions according to the current road conditions. Besides this intra-vehicle communication from sensor to a display, wireless communication will be used to support vehicles equipped with the LIWAS system to inform each other about the state of the road being approached. A communication infrastructure is required to support this inter-vehicle distribution of road-state information.

Figure 1 shows the basic operation of the LIWAS system in a typical road scenario. The figure shows a road with two opposing lanes and an icy section (indicated in grey) crossing both lanes. The dashed arrow represents wireless communication among the vehicles. The figure is explained below.

[1] http://www.liwas.com

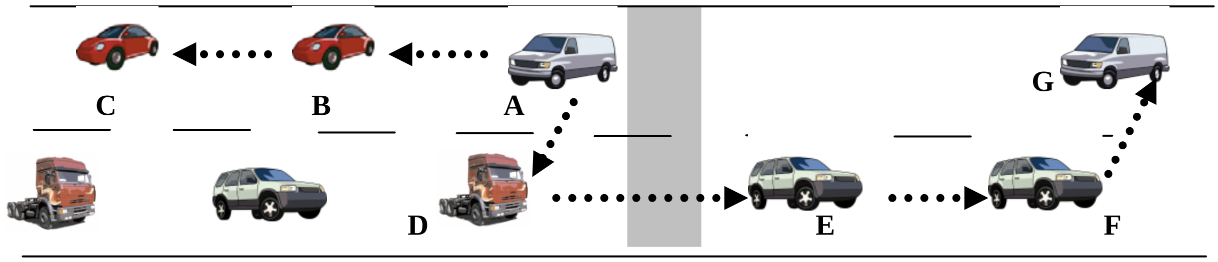

Figure 1. Basic operation of the LIWAS system

Vehicles in the top lane travel towards the left, whereas vehicles in the bottom lane travel to the right. Vehicles passing the icy section will detect ice and pass this observation on to other vehicles. As an example, when vehicle A detects that there is ice on the road, this observation will be passed to vehicle B that in turn passes the observation to vehicle C (and so on). In this way, vehicles will be aware of the icy section when approaching it, and hence be able to take the necessary precautions in advance. The vehicles D, E, F travelling in the opposite direction of A can be used as intermediate hops for warning vehicle G approaching the icy section from the right.

We are currently researching and developing the *Ex Hox* communication infrastructure to support scenarios such as the above based on principles of ad-hoc networking [1]. This paper provides an overview of the components in the Ex Hoc communication infrastructure and discusses the overall design.

The rest of the paper is organised as follows. Section 2 provides an overview of the Ex Hoc communication infrastructure. Section 3 considers intra-vehicle communication, Section 4 considers communication outside Ex Hoc nodes, and Section 5 considers inter-vehicle communication. Finally, in Section 6 we sum up the conclusions and provide an outlook on future work.

2. Infrastructure Overview

Cars, trucks, road signs, and traffic lights are typical examples of LIWAS nodes. LIWAS nodes represent the entities which LIWAS sensors and communication devices can be built into. Not all LIWAS nodes have the same capabilities, e.g., not all cars have LIWAS sensors. The only thing they have in common is that they all have some kind of communication system, i.e., intra communication and inter-vehicle communication. The main goal of the Ex Hoc infrastructure is to support the dissemination of information to vehicles about the state of the road. A vehicle that registers anomalies on the road has to distribute this information using an inter-node communication system.

The LIWAS communication system can be realised in many ways ranging from a centralised architecture based on, e.g., GSM or GPRS networks combined with web servers, to a decentralised architecture based on ad-hoc networking and multi-hop communication among vehicles. In a centralized network architecture, the data collected by LIWAS nodes is sent to central servers for processing. Interested LIWAS nodes receive information about the state of the road from the central servers.

Figure 2 illustrates an example of how a centralized LIWAS system could be built. Road sign A is a stationary LIWAS node with a sensor. Car B is a mobile LIWAS node with a sensor and car C is a mobile LIWAS node with or without a sensor. The figure shows how a car can receive information about the state of road from a Wireless Wide Area Network (WWAN) station such as a base station in a GPRS network. Once the information reaches the car, the information is communicated to the driver using an in-car communication system. The different steps the data takes before it reaches car C are numbered in figure 2 and each step is described below:

1. Road sign A measures ice on the road. It then sends data about the state of the road to the central server, e.g., a web server.
2. Car B measures the ice on the road while passing the icy zone. It then sends data about the state of the road to the central server using a wireless connection. In this case, car B uses a WWAN connection.
3. Car C receives from the central server the data collected by road sign A and car B. If the data received indicates that the condition of the road ahead is icy, the warning system informs the driver before reaching the icy zone. This assumes that the position of car C is known, e.g., using GPS
4. The driver in car C can now take the necessary precautions to drive safely over the ice, e.g., reduce the speed of the car.

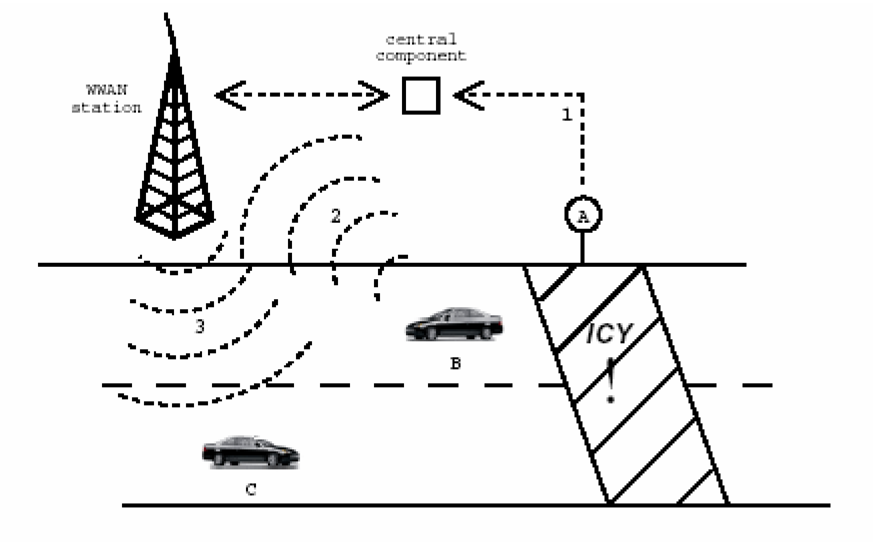

Figure 2. Operation of a centralized architecture

In a decentralized network architecture, communication will be based on the principles and concepts of ad-hoc networking. Data is distributed directly to interested LIWAS nodes in a peer-to-peer fashion where each peer is a LIWAS node. Figure 3 shows an example of how a decentralized LIWAS system could be built. Road signs A and B are stationary LIWAS nodes with a sensor. Car C is a mobile LIWAS node with a sensor. Car D and E are mobile LIWAS nodes with or without a sensor. The figure shows how a car can receive information about the state of the road. Car E is the one which receives warnings from other LIWAS nodes. Communications among nodes is accomplished by WLAN technology, e.g., WiFi/IEEE 802.11 [2]. Once the data reaches car E, the driver is informed by the in-car communication system. The different steps the data takes before it reaches car E are numbered in figure 3. The same figure shows that the decentralized network architecture is usually based on multi-hop communication. A description of each step follows:

1. Road sign A measures ice on the road. Data with information about the icy zone is sent to road sign B.
2. Road sign B receives the data and forwards it to nearby cars, in this case car E.

3. Car C also collects data about the icy zone while driving over it. The data containing information about the icy zone is distributed to other LIWAS nodes in range of the sender, in this case car D.
4. Car D receives the data from car C and it forwards it to car E.

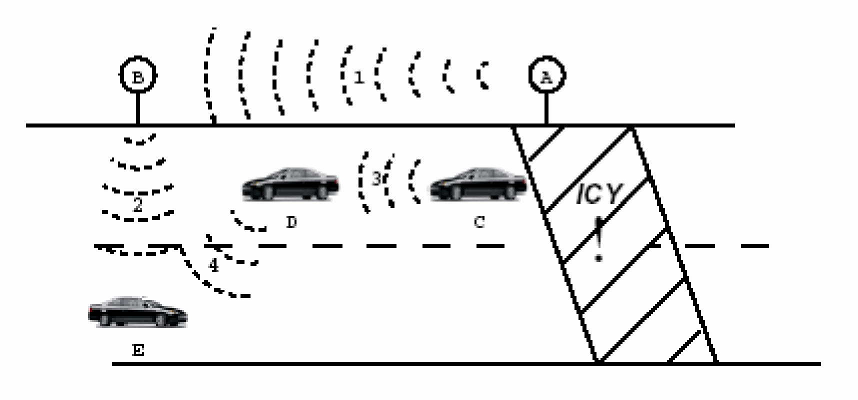

Figure 3. Operation of a decentralized architecture.

The two architectures presented above each have advantages and disadvantages. The centralized architecture has an advantage in coverage since, e.g., the GSM network has full coverage of roads in most countries. The main disadvantage of the centralised architecture is scalability since the servers need to be heavily replicated to handle processing of many requests. Also, there are price issues in using proprietary networks for communication.

Conversely, the decentralised architecture has an advantage in scalability, but has a problem when the density of vehicles equipped with the LIWAS system is low or when there is partitioning in the network topology. Also, it may be technically more complex to build than a centralized version.

As a consequence of these issues, we are developing a hybrid infrastructure framework, *Ex Hoc*, which combines central and decentralized network architectures. The LIWAS system may be seen as an instantiation of this framework. The basic idea is to rely on direct communication between nodes when possible, and only rely on the centralised network when strictly required. This leads to the introduction of *communication gateways*. A communication gateway is an Ex Hoc unit capable of connecting the local inter-node communication to the global centralised communication system, e.g., the GSM network.

Figure 4 illustrates an example of how a LIWAS system can work on top of Ex Hoc. Car A is a mobile LIWAS node with a sensor. Car B is a mobile LIWAS node with or without a sensor. The figure shows how a car can receive information about the state of the road, from a WWAN station or via another LIWAS node:

1. Car A measures ice on the road when passing the icy zone. It then sends data about the state of the road directly to car B
2. Car A sends also the data to the central server.
3. Car B receives data from the central server.

In this example it is not strictly required that car B receives data from two different sources, however it may be configured to do so using Ex Hoc. In this case, car B could restrict the use of the network to nearby cars, and if no cars were in the vicinity, car B could request information from the central server using the centralized architecture as a fallback mechanism.

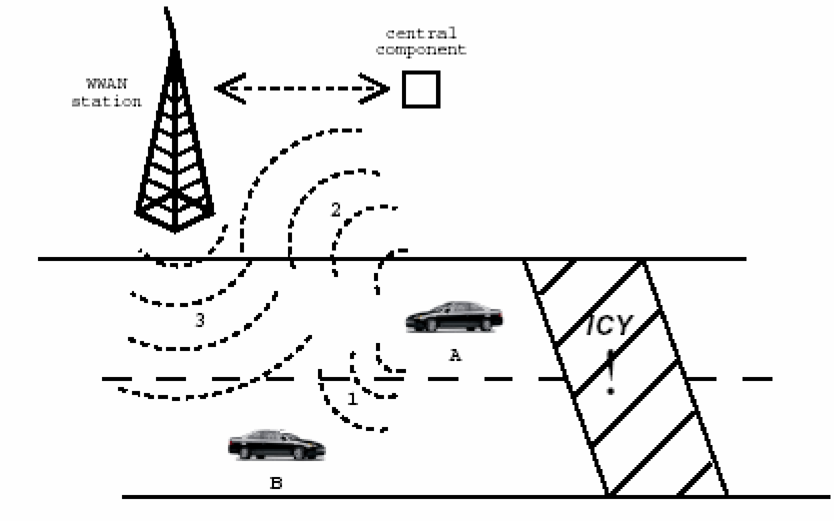

Figure 4. Operation of a hybrid architecture

2.1. Implementation

Figure 5 shows a view of a running Ex Hoc system in Unified Modeling Language (UML; [8]) notation. The mobile nodes contain a Sensor System and a Communication System. The Sensor System, which is very close to hardware, is implemented using the C programming language on a micro-controller and interfaces to the Communication System via serial cable. The Communication System is implemented using the OOVM Resilient platform for small embedded devices[2]. The Resilient platform provides among others capabilities for remote monitoring and serviceability of systems [8].

Currently, stationary nodes are basically reconfigured mobile nodes, and there are no backend nodes.

[2] http://www.oovm.com

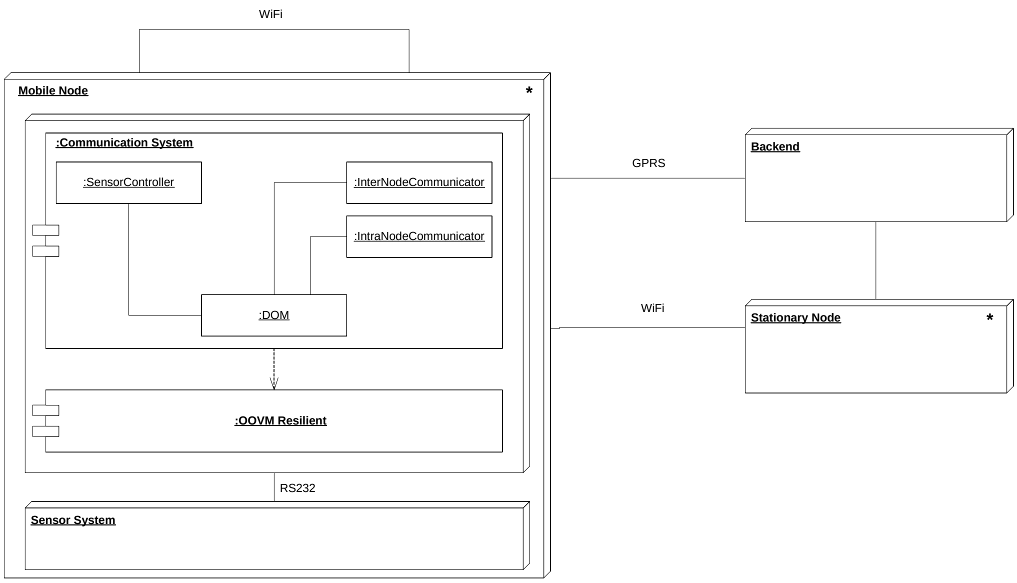

Figure 5. A Runtime view of an Ex Hoc system. Three-dimensional boxes show computational nodes and boxes inside these show software components. Lines between boxes are communication connections.

3. Intra-Node Communication

Vehicles and road-signs equipped with a LIWAS sensor continuously make observations about the state of the road. Thus, cornerstones of the LIWAS system are to sense environmental information, classify the sensed information, and communicate this information within vehicles. This section present these aspects of the LIWAS system.

The LIWAS sensing system is based on among others principles of optical reflection, enabling the collection of sensing data in highly mobile as well as stationary systems. Data from various sensors is combined, and based on this combination, classifications of road conditions are made online. In the in-vehicle system, the LIWAS sensing system will potentially provide a classification for each meter at 130 kph.

Currently, the LIWAS sensing system exists in a number of experimental versions. One of these is a car trailer equipped with a large number of sensors (including reflection, spectroscopy, temperature, humidity, and height sensors). This trailer is used for collecting data in various road conditions in order to create algorithms for classification. Furthermore, the first prototypes of a LIWAS sensor which may potentially be installed in a car have been produced. The LIWAS system is able to reliably classify the collected data in relevant road conditions based on a subset of the sensors from the trailer. The classification is done using pattern recognition based on standard linear discrimination [10, 11].

After classification, information on local classifications as well as information received from other nodes needs to be displayed to the driver. The current version uses a display in the vehicle and cabled serial communication. We are also building wireless intra-node communication based on Bluetooth[3]. This allows for more flexible intra-node communication to devices such as mobile phones which may be available only temporarily. This is further described in the next section.

[3] http://www.bluetooth.com

4. Extra-Node Communication

To enable communication outside an Ex Hoc-based system, we use *gateways* to bridge the communication to outside units. We are currently developing a LIWAS mobile gateway in the form of a mobile phone. This mobile gateway provides user interface as well as internet connection capabilities usable through Bluetooth.

The user interface of a mobile phone provides advanced interaction capabilities including graphics, sound, and vibration which may be used at least to prototype flexible user interfaces for the LIWAS system. It is unclear how it affects traffic safety to use a mobile phone to, e.g., give warning sounds and how suitable mobile phones are for this kind of application [12]. The internet connection capabilities may be used to, e.g., connect to a central server as described above.

5. Inter-Node Communication

These observations made by Ex Hoc nodes must be distributed to other nodes, but only in a limited geographical area around the origin of the observation. Distribution of observation in a limited geographical area is required to reduce the load on the communication infrastructure and to avoid distributing the observations hundreds of kilometres away to vehicles and nodes that will never enter that section of the road or will not enter it until much later. The geographical region where the observation is distributed should not be too large since that would put unnecessary load on the communication infrastructure. On the other hand, it should not be too small as the vehicles need to be warned in time before entering, e.g., a slippery section of the road. The above considerations has led to the concept of *zone flooding* that uses a flooding protocol to disseminate observations about the road-state, and uses geocasting [4] to limit the dissemination to a geographical zone around the location of the observation. Zone flooding can be viewed as a special case of flooding-based geocasting [7] where the source is located in the geocast zone.

The development of the inter-vechicle and inter-node communication subsystem is being approached top-down and bottom-up. In the bottom-up approach, we are developing a prototype test-bed based on UDP communication [5] on top of WiFi communication. The first prototypes demonstrating vehicle-vehicle and vehicle-roadsign communication have recently been tested on a highway with speeds up to 130 kph. These experiments have demonstrated that sufficient information can be exchanged between LIWAS nodes even at high speeds.

The experiments with prototypes in the real environment where the LIWAS system will eventually be deployed are limited to small-scale evaluations of the LIWAS system due to the difficulty in orchestration of vehicles and equipment. In the top-down approach we are therefore developing a simulation model using the Network Simulator 2 [6]. This simulation model makes it possible to evaluate the performance of the communication infrastructure on different traffic scenarios and it enables comparison of various design alternatives. Evaluation of various flooding protocols for data dissemination in the LIWAS system is currently ongoing. Some initial results can be found in [9].

6. Conclusions and Future Work

The Ex Hoc infrastructure framework and the LIWAS application thereof will potentially enhance traffic safety through intra- and inter-vehicle awareness of road conditions based on reliable classification and dissemination of this classification. Further applications of the Ex Hoc infrastructure includes other systems in which mobile and stationary units are sensing their environment and need to communicate in hybrid ways. Further applications of the LIWAS system include possibilities for lessening environmental strain through knowledge of road conditions, e.g., to enhance effectiveness of salting icy roads. Moreover, applications of centralized data dissemination include web page overviews of certain areas or subscriptions to SMS services based on location of mobile phones and condition of roads in that location.

Acknowledgements

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[4] http://www.isis.alexandra.dk