The Application-Based Clustering Concept and Requirements for Intervehicle Networks

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ABSTRACT

A new network clustering concept for foresighted driving applications is introduced, taking into account the specific requirements for highly dynamic intervehicle networks. Considering initially low system penetration in the market, the concept includes so-called message relay boxes without backbone network connection for temporary roadside storage of messages. The article differentiates between moving and quasi-stationary applications and explains how clusters tied to specific geographic locations will lead to even more complicated mechanisms for topology management in clustered ad hoc networks. A proposed message handling algorithm for cluster establishment shows the complexity needed to guarantee overall data consistency and network reliability as required for safety-relevant cooperative systems.

INTRODUCTION

Considering 40.000 road fatalities every year in Europe, the European Commission has launched the e-Safety initiative aiming to reduce this number by 50 percent until 2010. Several car manufacturers, automotive electronics suppliers and Universities are working together to develop new electronic systems for accident prevention, collision mitigation and protection of vulnerable road users such as pedestrians and cyclists. US investigations claim that 17 percent of crashes could be prevented if the majority of vehicles was equipped with warning equipment. The E-safety report relates 30 percent of all crashes to intersection/crossing paths and expects reduction through advanced driver assistance systems ranging from 37 percent for lane change/merge, 20–30 percent for head-tail collisions and 5–10 percent for poor vision. These accident scenarios are addressed by improved sensor technology and additional intervehicle communication (IVC). While sensor technology is limited to distances of about 150 m, IVC extends this range and allows foresighted driving [1], leading to early driver alerts and decreased reaction times (Fig. 1).

Safety-related IVC will be restricted for the foreseeable future to warning systems only, until sufficient market acceptance has been reached, and all liability issues have been solved which come into view as soon as vehicle control systems are actuated. In the context of the European Integrated Project PREVENT [3] (on preventive and active safety applications), a wireless local danger warning (WLDW) system allows cars to inform each other of road dangers, adverse weather conditions, or obscured obstacles and traffic jams. Obviously, danger warnings are not the only kind of information that can be interesting for a driver. Traffic density and average speed are examples of real-time telematics information that can be used by navigation systems for turn-by-turn decisions as an enhancement to infrastructure-based information through a traffic message channel, digital audio, or satellite broadcast. To cope with the slow penetration ramp up for communication equipment and also considering vulnerable road users (e.g., at dangerous intersections), safety-related IVC systems will also have to interoperate with roadside sensor networks and infrastructure [4]. Therefore, major road safety stake holders in the United States have set up the vehicle infrastructure integration project promoting the usage of 5.9 GHz dedicated short-range communication (DSRC) technology as recently granted by the FCC for roadside safety applications.

This short-range communication refers to a typical communication range of about 200–300 m line of sight, possibly extensible to 1000 m by means of specific antenna configurations and high transmission power. The relatively short duration of communication, especially considering oncoming traffic, demands:

- A simple broadcast message dissemination scheme with very little time to negotiate a connection setup or even specific link parameters
- A multihop rebroadcast facility to guarantee a certain time to live for each warning message

Such a scenario is depicted in Fig. 2, also indicating that the limited communication range and node mobility require intermediate relay stations, so-called *message relay boxes* (MRBs), close to the zone of relevance to store messages for subsequent forwarding to other approaching vehicles.

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In this scenario, the sensors of a vehicle passing an accident recognize the potential hazard. An obstacle warning message is broadcast several times and reaches the oncoming vehicle equipped with vehicle-to-vehicle communication. Smart message dissemination algorithms will tie into the navigation system and determine whether or not a vehicle will pass the zone of relevance and is therefore qualified as a message retransmitter.

To make the system more attractive for early adopters, it is necessary to link the warning application to commercially available services and roadside hot spot applications, which are usually based on peer-to-peer link setup along with association and authentication. This will enable communication between vehicles and a stationery roadside unit, for example, to download map updates. Dedicated peer-to-peer links will also allow specific intervehicle applications where vehicles dynamically form clusters, as is the case in highway platooning or cooperative adaptive cruise control.

In this article we propose a concept to address three issues related to short-range communication for safety-related applications:

- How to cope with large intervehicle gaps in sparsely populated vehicular networks due to either low penetration rates of intervehicle communication equipment during market introduction or certain road/city topologies
- How to deal with isolated clusters of vehicles and improve the organization of these clusters in order to reduce message delivery delays
- How to ensure consistency and improve communication reliability of safety-critical data in cooperative collision avoidance applications

The article is organized as follows. We describe application requirements and specific characteristics for foresighted driving. Then we discuss the concept of the MRB. Next, we introduce new clustering concepts for vehicular networks; this is followed by some conclusions.

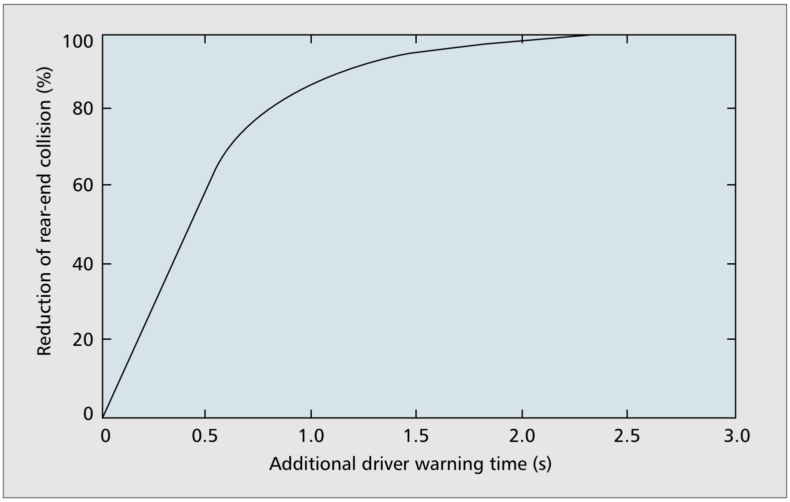

Figure 1. *Providing a driver with an additional 1 s of warning time to react can reduce rear-end collisions by nearly 90 percent [2].*

Application Requirements and Related Work

The proposed vehicular warning system can be considered a special kind of wireless sensor network, since sensor data are exchanged among vehicles, such as vehicle speed and acceleration, collision radar, crash detection, and vehicle density. Nevertheless, vehicular mobile ad hoc networks (MANETs) face a number of new challenges, in particular due to the extremely dynamic network topology and a large variable number of mobile nodes. European and national research projects like FleetNet, CarTalk2000, Invent, and NoW [5] have been launched to study the particular aspects of geocast routing and quality of service for Internet on the road. Furthermore, safety-relevant vehicular networks deviate from the classical MANET research focus since they are not hampered by limited power and also will not allow in-network processing and distributed data storage due to liability restrictions.

With respect to traditional WLAN concepts, the WLDW application demands extremely low latency for relatively short messages. Reference [6] gives an overview of the application requirements for IVC in general, an applicable subset of which is discussed in this section.

WLDW belongs to the class of driver assistance ("comfort") functions with a service range of 300 m up to several kilometers, delivering real-time informative messages to drivers who always remain in control. As long as automatic vehicle control is not derived from message content, the reliability requirements are medium, and liability issues will not block market entry. Penetration rate is a critical issue, since WLDW is assumed to be one of the market openers for IVCn, with migration opportunities to a wireless LAN (WLAN) type vehicular ad hoc network.

A warning message of typically 200 bytes should be communicated with a maximal delay of about 500 ms and kept alive by means of rebroadcasting, sometimes called *cyclic repetition*, in its specific zone of relevance. Besides event-driven hazard warning messages, regular beaconing by means of Hello messages every 100 ms is usually applied to allow:

- Anticipation of potential collision dangers
- Deduce vehicle density in the vicinity
- Convey continuous position updates for platooning and cruise control applications
- Provide a neighbor list for selection of multihop forwarding nodes [7]

Unless government regulations demand large-scale deployment of communication technology in vehicles, the system will start initially in small numbers. However, from the beginning the system must be designed for a large density of communication nodes, as is the case in rear-end traffic jam collisions, where low-priority communication of jammed vehicles may block the transmission of safety-relevant warnings. Rebroadcast strategies in these scenarios will obviously lead to broadcast storms demanding some form of high-level congestion handling or other means of restricted flooding (see [8] for an extensive overview of existing work). One form of high-level congestion handling are protocols that automatically reduce the generation rate of emergency messages in the event of an accident [9].

In case of very low traffic density, the distance between communication nodes can be too large and message transfer can be difficult. Little work has been done so far to cope with this problem from a system architecture point of view, although some network protocols assume the existence of roadside infrastructure elements. For example, [10] introduces infrastructure-based servers as part of the stored geocast protocol, allowing persistent messages to be generated that are bound to a certain geographic area and valid for a predefined time period or even endlessly. Other approaches include infrastructure elements to bridge IVC gaps [11]. These elements need backbone interconnection to some kind of public or private network where the central message processing is done. From there, updated traffic status is fed back to the vehicles or roadside units via broadcast media. Some of the concepts constitute a shared database including the roadside units, thereby relying on the fact that the vehicles know about the existence of it and are able to address it using sophisticated routing and location algorithms.

The concept outlined in this article proposes to reuse vehicular communication modules in portable beacons with or without a wireless interconnection for the purpose of storing, relaying, and processing warning messages. Interconnection of these MRBs is not precluded and may be based on existing wireless protocols such as IEEE 802.16 (WiMax). This will improve the coverage of network nodes to allow market introduction of a wireless local danger service, without huge investments in roadside infrastructure.

The WLDW concept further anticipates the need to group vehicles into:

- Virtual caravans (*platoons*), groups of vehicles pursuing the same direction for a decent amount of time
- Quasi-stationary clusters aimed at cooperative decision making among fluctuating network participants

Most of the group communication research [12] is dedicated to the first type, while the notion of quasi-stationary clusters is not yet publicly disclosed to the authors' knowledge. This article only describes the basic principles, admitting the need for more intense research efforts on cluster controller selection, cluster interference, and numerous cluster administration tasks, as already highlighted in [13].

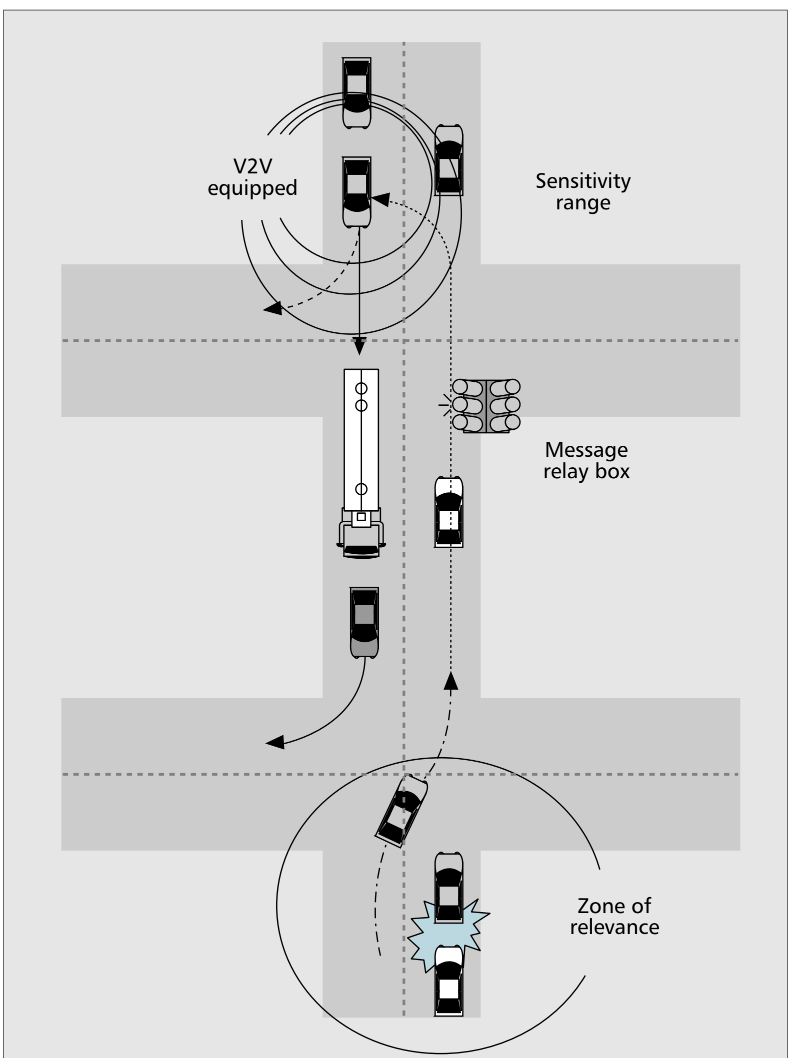

Figure 2. *Overall local danger warning system.*

Message Relay Box

The MRB is a stationary roadside unit, compatible with vehicle communication subsystems, meant to store messages from passing vehicles without them being aware of this and relay these messages to other vehicles later in time, thereby keeping the message alive within the zone of relevance. Incoming messages can be accumulated, duplicated messages can be filtered out, and more complex messages can be created autonomously and processed without the need for a central control center.

The MRB does not require a connection to the roadside network, either physically or logically, and is arbitrarily placed along the road, resembling a virtual parked car. There is no need to address the box, and vehicles do not rely on its existence. Powering should be fairly easy by either attaching it to public road infrastructure, requiring intervention and control from road authorities, or placing them standalone and powered by solar panels, in which case the service provider or highway operator would be responsible for maintenance and administration.

Installation may start at densely frequented locations with sufficient preventive safety potential and may ultimately lead to a meshed network of intersections equipped with portable infrastructure devices.

According to Fig. 3, the MRB is composed of an intervehicle message receiver/transmitter, an optional transit link for wireless interconnection to the backbone network, a message processing unit for smart filtering of messages, the information database storing the context and sensor information for warning interpretation, and the message database for received and transmitted danger warning messages. Messages and information received from the message processor and filter unit are stored in the database, periodically controlled and eventually reprocessed in order to update information already present in the database with new messages and remove outdated messages. An automatic proximity detector may be employed to power up the device from standby mode if a vehicle is approaching. The indicated controllers use typical message parameters like time to live, priority, reliability, vehicle identification number, and vehicle position to cancel, merge, or update information and messages.

Information and message database controllers are equipped with an application control interface, which allows overall prioritization setting depending on driver distraction control parameters and environment parameters such as approaching a hazardous location, emergency vehicle approaching, police enforcement, or simply network overload. In some of these cases it is desirable that all low-priority traffic is prohibited and the corresponding message queues are flushed in order to have the maximum channel capacity available for high-priority traffic. This application-level congestion control may also be used to lower the retransmission repeat rate or duration. The application also determines the need for retransmission of certain messages, specifies the time and range boundaries, and enables the appropriate restricted flooding schemes residing in the message database controller. Other parameters of the application interface are a list of codes for messages to be filtered for duplicates received from other nodes. Furthermore, the information database controller needs to be programmed with trigger points to notify the application, where the most obvious example is actuation of the crash sensor. Specific tasks for automatic message generation and beaconing are foreseen as well as receive handlers for special messages like:

- Request for device status (maintenance status, battery lifetime, etc.)
- Request for road and safety status (type/time of accidents and hazards reported)
- List of generated messages (activity tracking)
- Configuration message (for authorized personnel, initialize, identify, self-test)

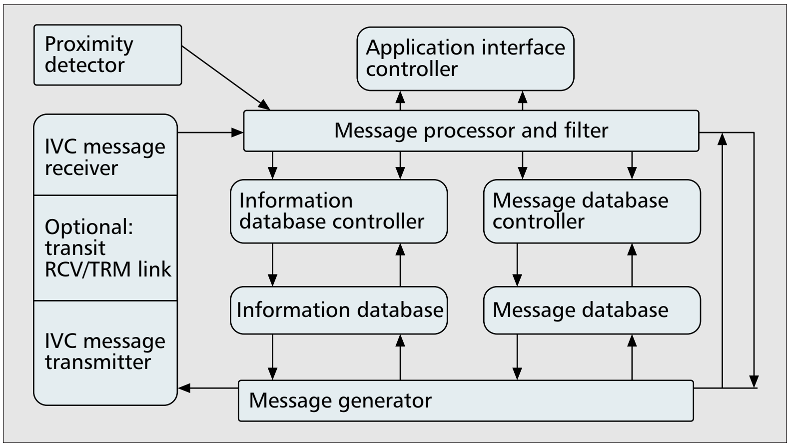

Figure 3. *The communication subsystem of a message relay box.*

Clustering in Vehicular Networks

Vehicle-to-vehicle communication topologies are subject to traffic rules and road environments. In a typical highway scenario vehicles moving in the same direction have a relative mobility that allows connection periods longer than 30 s (considering a relative speed of up to 100 km/h and a radio range of 500 m), which is long enough to guarantee a sufficient level of stability for cluster organization among neighboring vehicles.

While a lot of research is being invested in cluster setup, cluster controller selection, and cluster merge and join procedures at the network level [14, 15], we introduce the concept of clustering at application level. This application based clustering will allow different inter-vehicle applications to run at the same time, where every application may set up its own virtual cluster in order to optimize the exchange of relevant information. The main rationale for this approach are the requirements for safety-critical cooperative systems, which need highly dependable coordination and synchronization of car movements. In other words, the timing and sequence of messages, and the consistency thereof at all participating nodes is of crucial importance. Simple broadcast messages or unorganized exchange of unicast messages would not be reliable enough, and reaching a stable state might simply take too long.

In such a highly dynamic environment clustering based on centralized communication with a temporary cluster controller (CC) is a way to maintain consistency of data and avoid sophisticated voting mechanisms. The CC collects and processes information pertaining to a predefined application, such as obstacle avoidance, highway merge assist, or vehicle platooning (Fig. 4). After collecting all required information, the CC can transmit a set of consistent data to all nodes subscribed to the application cluster. This will provide consistent information management that is robust against changes in network topology, and by the way also reduces the channel load.

Once the controller of the cluster has been established, every time a node has relevant information it sends it directly to the CC, who will store all the data received from the nodes subscribed to its cluster in a local database and process them locally. The results of the process can then be distributed to all the other nodes. If a mobile terminal decides, based on sensor or navigation data or after the reception of a warning message, to subscribe to the application, it will be able to retrieve the latest up-to-date information from the CC.

Another advantage of having clusters organized by application is that every application can apply different rules to its clustering algorithm. For example, considering an intersection assistance application, the CC, responsible for collection of information and decision making, should be a node able to communicate to all vehicles approaching the intersection. This task could be best accomplished by a fixed node (e.g., an MRB) installed at the center of the intersection. Other applications instead may select their CC following rules like "closest to average speed" and "closest to hazard location." Moreover, besides the CC selection process, other functions like cluster merging and splitting would benefit by being differentiated for different applications.

Considering the technical issues to be solved, we propose distinguishing *moving clusters* from *quasi-stationary clusters*. In moving clusters, the application and associated CC move along a predefined road, and cluster subscribers have low relative speeds, while the network topology will

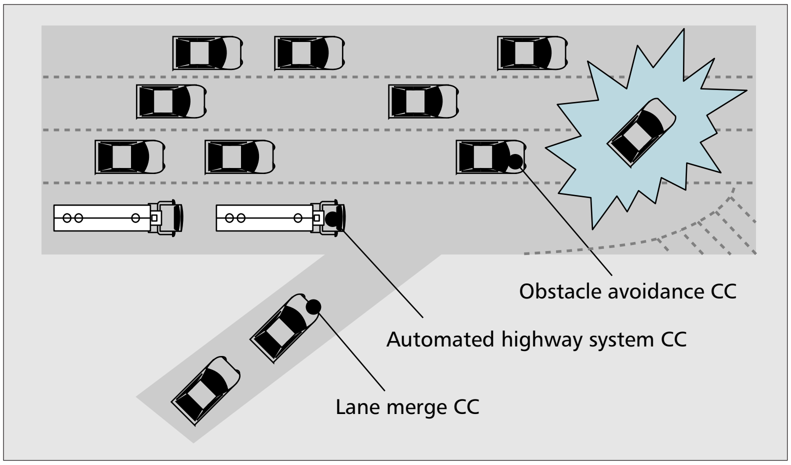

Figure 4. *Road scenario for application-based clustering.*

change as described above with vehicles leaving and joining the cluster. On the other hand, in quasi-stationary clusters the application demands a CC at a certain hazard or accident location (or more precisely, within the communication range of a specific geographic location), while the actual cluster subscribers as well as the CC are continuously replaced. This means that information collected by nodes that are leaving a certain zone remains available for other vehicles that enter the zone later in time. See Table 1 for classification of typical cooperative systems applications as moving or quasi-stationary clusters. In both cases, vehicles listen to the application services advertised by the CC and contribute relevant data after formally joining the cluster and identifying themselves to the CC. During this procedure, authentication data, encryption keys, and so on can be exchanged to improve reliability and security of data.

While most of the concepts on cluster administration can be applied to moving clusters, quasi-stationary clusters pose additional problems. When the CC realizes it is moving outside the connection range of its cluster, or its position is not suitable anymore to be the CC for that application, it needs to initiate the procedure of releasing its controller status to another vehicle. This is standard procedure, which implies reselection of a new CC and transfer of information from the old CC. However, due to the unpredictability of channel and driver behavior, the CC may terminate its connection before the releasing procedure is activated or terminated. This would lead to a complete loss of data, which will abruptly terminate the functioning of the current application.

To solve this problem, either of the following should be in place:

- A second fallback CC must be available that takes over responsibility.
- All nodes maintain a copy of the latest information sent to the CC, periodically deleting out-of-date or redundant messages.

The CC should therefore periodically broadcast its information to the cluster zone until it receives an acknowledgment that its message has been delivered or some other vehicle is acting as a shadow CC. If a permanent loss of connection to the CC occurs, the vehicles will reactivate the algorithm for CC selection and provide the new elected node with all the information stored in their local database. At this point the new CC will process the received data, eliminating out-of-date or redundant information.

Another general problem regarding loss of connection to the CC is to differentiate between the situation where the head moves outside the range of the cluster or the node itself exits the cluster. Since these situations appear to be indistinguishable from the nodes' point of view, we propose to treat them as a unique problem. In fact, in both cases the node will realize that one of its application is missing a CC and that the application must reactivate the CC selection procedure.

Furthermore, for quasi-stationary clusters the mobility issues are more severe, because the relative speed of vehicles with respect to a quasi-stationary CC is much higher. Therefore, fast association/disassociation procedures and CC selection algorithms are required.

An example of message exchange is illustrated in the message sequence chart in Fig. 5, depicting the case where vehicle A is alerted by a warning message, and then starts finding and joining an existing application cluster. By means of data exchange with the CC (vehicle B), a

Application	M/S
The lane merge CC collects information on a particularly dangerous highway location, and keeps track of trucks approaching, cars bypassing trucks, vehicles waiting to join the highway, and so on.	S
The road weather CC collects information on potentially dangerous road situations (slippery or bumpy road, wind, ice, fog, etc.).	S
The automated highway CC is in charge of a platoon of cars following along a specific path.	M
The rail intersection CC is informed about train arrivals and blocking of rails.	S
The collision avoidance CC is informed of all information related to the location, type of obstacle, severity, and status of a danger situation at a specific location *xy*.	S
The local danger warning CC is in charge of transporting a warning message to potentially interested vehicles that are about to enter a dangerous location.	M

Table 1. *Moving and quasi-stationary cluster applications.*

coordinated danger avoidance strategy can be established among various affected cluster participants. During this message exchange the CC leaves the scene and inquires transfer of the CC function. After receiving an error (or timeout) the inquiry procedure starts again, this time by resuming a valid connection that has been transferred to the new CC (vehicle C).

In order to prove the efficiency of the clustering concept and procedures proposed in this article, an SDL-based WLAN simulator along with a realistic mobility model are currently applied for a city scenario as well as a one-road motorway scenario.

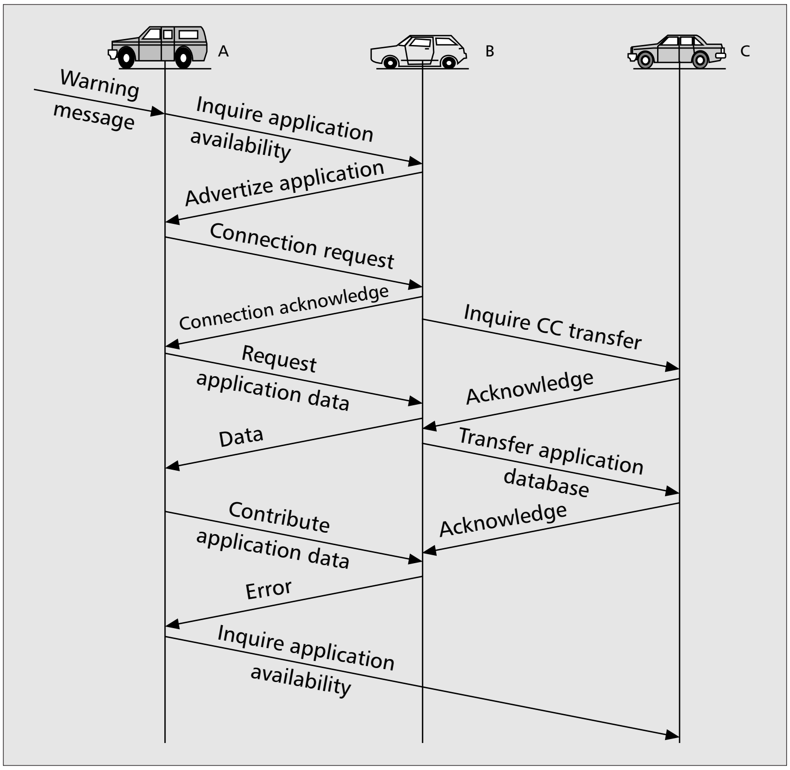

Figure 5. *Message sequence chart for application-based clustering.*

CONCLUSIONS

In this article we present a new concept to allow applications for increased road safety considering the initially low equipment penetration ratio. This is achieved by smart rebroadcasting of messages among vehicles, supported by compatible roadside units (message relay boxes) comprising a short-range communication system, able to store, process and forward messages received from passing vehicles. One of the major issues for cooperative systems is consistent message delivery to all vehicles pertaining to a particular application, such as obstacle warning or lane merge warning. The application cluster may be either moving or quasi-stationary. While moving clusters can reuse most of the existing concepts for cluster organization, taking into account the increased node mobility and network dynamics, quasi-stationary clusters with fluctuating participants at a fixed geographic location pose more severe challenges, such as the repeated transfer of the cluster control function from one vehicle to another in a very short period of time. High-level congestion control, application priority determined by external conditions rather than network-related conditions, and sophisticated message handling algorithms tied to the car navigation system will be important areas for future research toward dependable cooperative systems.

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