The IEEE 5th International Conference on Intelligent Transportation Systems
3 – 6 September 2002, Singapore.

A Peer-to-Peer Approach to Vehicular Communication for the Support of Traffic Safety Applications

Ioan Chisalita and Nahid Shahmehri, Linköping University, Sweden[1]

Abstract **- More than half a million casualties are due to traffic accidents each year. Therefore, there is a high demand for innovative technologies focused on collision warning and collision avoidance. Among such technologies, the inter-vehicle communication and the vehicle-to-road communication are considered to have extensive potential for supporting the safety systems located within a vehicle.**

In this paper we propose a new approach to vehicular communication. We have designed a safety-oriented vehicular communication, built around the concept of mobile ad-hoc peer-to-peer (P2P) networking. The merging between ad-hoc connectivity and P2P paradigm facilitates the development of a vehicular network characterized by self-organization, fault-tolerance, scalability, shareable resources and services, co-operation, ease of interconnection and cost efficiency. These characteristics recommend the communication proposed here as an efficient method for providing safety-relevant data for safety systems installed in vehicles.

I. INTRODUCTION

Traffic safety is a major issue for society [1][2]. Statistics [3] show a worrying increase of the casualties and damages due to traffic events. For example, in European Union alone, more than 3.5 million injured people and more than 160 billion EURO in material loses are reported each year [4]. Consequently, there is a special interest in developing Intelligent Transportation System (ITS) services for individual vehicles [5] that will lead to a reduction of the critical traffic events. Examples of such services are collision warning and collision avoidance. These safety services utilize a variety of static and dynamic data obtained from host vehicle, the road, and other vehicles that participate in traffic. It is predicted that the introduction of such safety services will lead to at least a 20% decrease in the average number of accidents [5][6]. As stressed by many researchers in [7][11][12][13], vehicular communication, both among vehicles (IVC) and between vehicles and the side-road (VRC), is expected to bring extensive support for the safety ITS services.

An example is presented in figure 1, which illustrates both IVC and VRC. In this case there are four cars on a road and a fixed entity on the side-road. Using the IVC, the vehicles having the same heading such as V1 and V2 exchange information related to their traffic situation (e.g. position and speed, brake and steering wheel status). On the other side of the road, the vehicle V3 communicates using VRC with the fixed entity E and receives data about the road characteristics. Also, E can be used to relay specific data from V3 to V4 if V4 is too far from V3. Further, the vehicles that meet, such as V2 and V3 can also exchange different data. Thus, some of the data are useful for all vehicles whereas other data may be useless or even misleading for certain vehicles. Consequently, there is a need for dynamically creating communities where the traffic participants can exchange information that is relevant for their traffic safety. These factors must be considered in the design and development of effective vehicular communication models and systems [7][17].

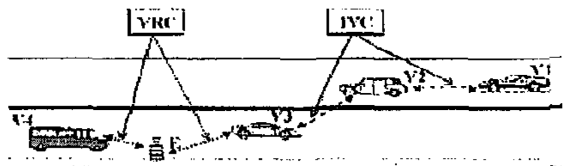

Fig 1. Vehicular Communication - example

In this paper we propose a model for organizing the vehicular network. This organization aims to overcome the lack of addressing within the vehicular network and allows the traffic participants to have relevant data with respect to the current driving conditions. Furthermore, this design aims at providing only the information that increases a driver's awareness in traffic. The organization of communication eases the detection of useless and misleading data, thereby improving information management. Moreover, within this approach the need for retransmission and routing is minimal and the utilization of the communication channel is improved.

The model that we propose introduces the concept of ad-hoc peer-to-peer (P2P) networking for mobile communication considering the specific characteristics of vehicular communication. The integration of these techniques can lead to the development of a vehicular network characterized by

[1] The authors are with the Department of Computer and Information Science, Linköping University, SE-581 83, Linköping, Sweden
E-mail: ioach@ida.liu.se, nahsh@ida.liu.se
Phone, Fax: +46-13-28-2452, +46-13-28-142231

self-organization, fault-tolerance, ease of interconnection, scalability, shareable resources and cost efficiency.

The rest of the paper is organized as follows. Section 2 presents the main features of the proposed vehicular communication. Section 3 describes the specific organization of the vehicular network. Section 4 contains comparisons between related works and our approach. Finally, section 5 presents some of the limitations associated with our proposal, summarizes the paper, and presents our conclusion.

II. FEATURES OF THE VEHICULAR COMMUNICATION

The proposed vehicular communication integrates four main features: ad-hoc connectivity, P2P networking, short-range communication and inter-personal communication.

Ad-hoc connectivity assures the self-organization of the vehicular network and its independence from a fixed infrastructure [8]. These are major advantages considering the dynamics and ubiquity of the traffic environment. Also, the utilization of ad-hoc connectivity supports the development of a fault-tolerant network since the communication is self-organizing and is not dependent on any dedicated base station or server. Moreover, there is a good potential for achieving a low cost for the equipment and service.

The second feature is mobile peer-to-peer networking. The traditional P2P technology [15] implies that the parties belonging to the network interact as equals and there are no central units for managing the exchange of information. The mobile P2P concept defines the application of P2P networking methodology in mobile environments. P2P is a network-based computing technology [15] that improves certain operations such as information discovery, content delivery and information processing. Moreover, utilization of P2P can lead to the enhancement of the reliability and fault-tolerance of computing systems. Three main properties characterize this technology: flexibility of interconnection, expansion of the bandwidth, and enhancement of computing and storage capabilities [16]. These properties also characterize the mobile P2P systems, although there are certain limitations associated with the restricted bandwidth of wireless systems and the limited processing and storage capabilities of mobile devices.
Dynamic discovery and sharing of resources and content are also benefits of mobile P2P systems. When applied to the vehicular domain these lead to the possibility for a traffic participant to use services and resources offered by other participants. Further on, effective collaborative applications can be developed based on information and service sharing. In the context of such sharing, the vehicles and fixed entities belonging to the side-road can efficiently interact for identifying dangerous situations and avoiding accidents.

In our proposal, the vehicles and fixed entities belonging to the roadside communicate via the ad-hoc mobile P2P mechanism and exchange messages that contain data relevant to traffic safety. This data describes vehicle motion characteristics such as speed and heading as well as road characteristics such as slipperiness. The messages may also contain warnings and infotainment data such as hospital locations. We have selected short-range radio communication for the physical exchange of messages. The characteristics of this technology recommend it for utilization within a mobile P2P network. Also, this technology allows high data rate and efficient management of the radio interference. Since IVC is combined with VRC, the vehicular communication have to accommodate different types of wireless media such as dedicated radio systems, RF beacons, IEEE 802.11, Bluetooth or infrared (IrDA). Technologies other than short-range communication, such as cellular and satellite, have been analyzed and we consider them as being less appropriate for integration with the mobile P2P approach. Further we have limited the communication area to 300 meters, area that is also specified by other researches [7][9] addressing short-range vehicular communication.

Although our design is mainly intended for the exchange of traffic safety data, the vehicular network can also be used for interpersonal communication. This type of communication is predicted to have a high demand from the users [14]. The inter-personal communication requires the exchange of drivers' profiles for finding common interests. When a match is found, applications that suit the specific profiles can be employed. The data contained within the profiles can also be used for providing assistance for urgent medical and mechanical situations.

III. VEHICULAR COMMUNICATION

A. Organization of Communication

We are mainly interested in the communication takes place in the support of ITS safety services such as collision warning and collision avoidance. Therefore, the vehicular network is organized with the goal of facilitating the exchange of short messages between the traffic participants. These messages contain data that are used by safety systems installed in vehicles for determining the risks associated with a traffic situation and informing the driver about it.

In designing the communication architecture we have considered a series of specific requirements that characterize the traffic environment. The most important were the need for high availability and high data rate, the real-time data exchange and the fast dynamic organization of the communication. Moreover, the traffic environment is characterized by a large variety of topographies associated with roads and highways, a predominant collaborative nature, and regulations or traffic laws. All these aspects not only affect the design of the vehicular network but they also require specific organization for the exchange of information.

The proposed communication does not require the existence of an infrastructure associated with the roads and therefore can be used on any road. Also, we propose to merge IVC and VRC for making possible to provide a seamless integrated environment. Even if IVC alone can assure the vehicular communication functionality, we believe that VRC can be extensively used for enhance this functionality. Thus, within our approach the vehicles and entities belonging to the side-road such as infotainment servers or relays are part of the same vehicular network and are called vehicular peers. Each peer has certain resources that can be shared and each peer can provide certain services to other peers. The network is organized using the mobile peer-to-peer (P2P) methodology and the peers utilize ad-hoc connectivity for exchanging messages that contain safety-relevant data. The peers are equipped with transceivers and can use different means of communication for exchanging information. Since the vehicular network requires high availability and in emergency cases is time-critical, we argue that a good approach is to broadcast the safety-related data. Thus, the traffic participants have the necessary data for organizing the vehicular network.

The peers are organized in zones in which they communicate named Peer Spaces (PS). A peer space is defined as a community of traffic participants that share a common interest. Further on, a peer belonging to a peer space maintains information about all the other peers from that area. A formal definition of these zones is given in the following. Let us defines a set V of vehicles and a set F of fixed peers. The elements of V are all vehicles equipped with vehicular communication equipment. The elements of F are relays and infotainment servers. Then, a peer space is defined as the set of peers that share a common traffic safety interest.

The interest is defined as a set of parameters given by the conditions that model the traffic situations associated with a peer at a given moment. The formal definition of a peer space PS_i is given below.

a) $PS_i \subseteq F \cup V$, $i \in N$, N the set of natural numbers

b) $\forall\, Y, Z \in PS_i$: Interest$(Z) \cap$ Interest$(Y) \neq \emptyset$

An example for the organization of traffic participants in peer spaces is illustrated in figure 2.

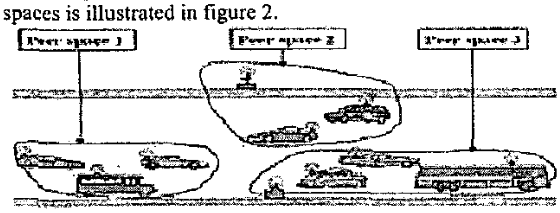

Fig 2. Peer space organization - example

The leading information used for defining the peer spaces is the positioning information. Therefore, all the peers have to be equipped with positioning devices that accurately indicate their location. We propose the usage of Global Positioning System (GPS), which is based on satellite communication. This is because the accuracy of positioning devices such as differential GPS (DGPS) can be less than a meter. Also, with regard to price, such positioning devices have lately become affordable. Moreover, these devices can use systems like dead reckoning (DR) for supplementing the possible temporary loss of satellite visibility. Certainly, other positioning systems such as those using magnetic sensors may be used as well.

Within the proposed vehicular network each peer maintains multiple positioning records and exchanges this data and other safety-related information with other peers. The positioning data are also used for determining a series of information such as the relative position of peers or if vehicles are travelling on the same road [12]. Further on, information about the vehicle status and the roads on which the vehicles are cruising are used for a more efficient organization of the vehicular network. Systems such as in-vehicle Geographic Information Systems (GIS) can provide some of these data.

Thus, the vehicles are organized in communication communities or peer spaces where they exchange information. However, for being able to determine a change in the peer space membership, a peer has also to analyze data sent by peers that may not belong to its area. Therefore, the peer space organization is dynamic and uses not only the positioning information but also other data addressing the driving situation. Also, we argue that different driving situations on different roads require different grouping methodologies. This is because even the safety requirements are different for certain situations and on different roads. For example, the braking distance for a vehicle traveling at 140 Km/h (e.g. 150 m) is several times longer compared with the distance needed for the same vehicle when travel at less than 50 km/h. Also, in the case of an urban area, the information from vehicles travelling in the opposite direction may be extremely valuable, but this may not be the case if vehicles travel on a divided highway. Therefore, we have considered three major issues for the organization of the peer spaces:

- The communication area
- The peer space composition
- Specific parameters of the driving situation

The communication area limits the peer space to the zone (e.g. 300 m) specific to the short-range communication. Furthermore, the peer space is not only space-limited but is also composition-limited. This is because for certain cases the communication area may include too many vehicles. For example, on a crowded urban street just one line of 300 meters long may contain more than 40 vehicles. It is unlikely that a peer will benefit by having data about all these vehicles. Therefore, we consider that the peers space composition should be limited. Thus, we have selected an upper bound of fifteen peers that can belong to the same peer space. This figure is high enough to comprise complex traffic situations and low enough to prevent information overload. The organization of the peer spaces also considers the following parameters addressing the driving situation:

- Peer positions, peer vehicle heading and speed
- Relative distance between peers
- Relative position of peer vehicles: vehicles traveling on the same road, behind or ahead each other, the road identity.
- Specific parameters addressing the driving situation: road slipperiness, driver and vehicle status
- Road type (if available): urban or rural road, intersection or regular road, divided or undivided road
- Additional road information (if available): speed limit on the road, road topologies (e.g. curve, elevation), road deficiencies and current working places.

These parameters are included in the messages exchanged between vehicular peers or are deduced from the data included in these messages. For example, the relative distance is calculated using multiple positioning records. Considering the above criteria, rule-based decision mechanisms have been defined for a peer to create, select and exit a peer space.

B. Peer Space Organizations

We have defined two main methodologies for the organization of the vehicular network in peer spaces:

- Cluster-based organization
- Peer-centered organization

The *cluster-based organization* considers the associative nature of the traffic for forming groups of peers with similar interests. This is because in many cases the real-life distribution of vehicles on the road indicates the grouping tendency. In this case, the vehicles decide that their traffic safety will benefit from this association and form the peer spaces. The decision is made considering the criteria previously mentioned. An example of four vehicles traveling on a road with divider is presented in figure 3. Here, vehicle V1 analyzes the messages sent by vehicles V3 and V2 and decides to join their group. Vehicle V4, which travels on the other side of the road, also analyzes the messages sent by V1, V2, and V3 but consider these data not to be valuable for him and therefore does not join their group.

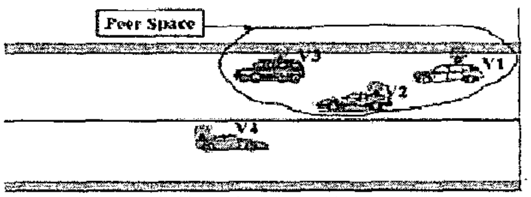

Fig 3. Cluster-based organization

Within the cluster-based organization each peer belonging to a peer space has to maintain information about all the other peers from this cluster. Thus, each peer has management functions and is responsible to join, leave and initiate a peer space. The joining and establishment of peer spaces is time-based. Thus, if a peer enters the traffic and does not receive in a certain time interval information of interest about a currently formed peer space, then it will initiate a new peer space. Otherwise, the peer will join an existing peer space.

The peer membership to a peer space is interest-dependent. With regard to traffic safety, the interest extensively depends on distance, meaning that vehicles in the immediate vicinity have important data. Nevertheless, we consider that not only the distance between vehicles, but also the components of the diving situations such as vehicles' headings and speed, relative position, road type, slipperiness and other factors have to be taken into consideration. Consequently, a vehicle will join another cluster if the data sent by peers belonging to this cluster is considered more valuable for it than the data sent by the members of the cluster in which is currently registered.

The members of a cluster maintain information about all other peers from the cluster. Thus, when a member leave the cluster the others need to remove the data associated with it. This can be done as a result of a leaving announcement sent by the leaving peer, or by using a time-based method. We propose the second alternative, which requires that a record associated with a peer be removed if these data are not updated within a certain time interval.

There is also the possibility for a peer to be a member of more than one cluster. We call this multiple membership and in this case a peer has to maintain data about all the other peers belonging to all the clusters in which the considered peer is member. This approach can allow a better analysis of complex traffic situations but may result in an overload of the communication and of data processing for a peer.

Further on, we have defined a particular organization called fixed cluster for specific places where the possibility of accident is high such as intersections or peek-ramps. This is because such places may extensively benefit from the installation of fixed peers that organize the communication. Thus, in order to have an accurate representation of the traffic situation, the vehicles approaching such places become part of these fixed clusters. However, they still belong to their previous established peer spaces and in this case the multiple membership is called group superposition and is managed by the fixed peers. An example is shown in figure 4, where the fixed entity E maintains a fixed cluster that overlaps the peer spaces previously formed by the vehicles.

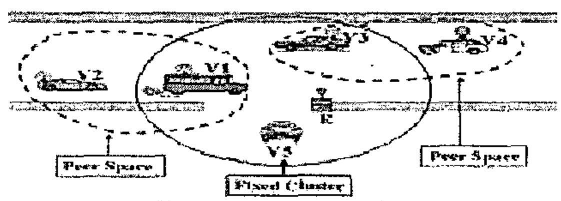

Fig 4. Fixed cluster organization

The major advantage of fixed clusters is that the vehicles have immediate information about each other and the topology of the area. The drawbacks are due to the need of developing a limited road infrastructure for applying this approach.

The other methodology for organizing the vehicular network is the *peer-centered organization*. This approach considers the individual nature of the traffic participants focused on avoiding accidents. Within this method, each peer defines, constructs and maintains its own virtual peer space (VPS). Thus, a peer analyzes the information received from other traffic participants and decides which of them should belong to its own VPS. This area is continuously updated and the organizer peer maintains information about all the peers belonging to it. Here, a fixed cluster is a VPS related to a fixed peer. Within this approach, different VPS overlap and the peers are responsible to sustain the global awareness by re-sending some of the data. An example is presented in figure 5.

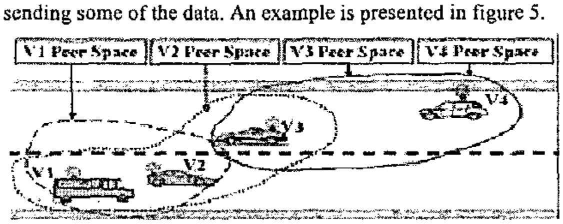

Fig 5. Peer-centered organization

In this case, each vehicle peer V1, V2, V3 and V4 create its own peer space according to its own traffic safety interest. For example, the vehicles V1 and V3 will be part of the V2 peer space, but only vehicle V4 is part of the V3 peer space.

C. Routing within Peer Spaces

As previously presented, the vehicular network is organized in communication areas where the traffic participants exchange messages. The relevant information is stored by each peer and is controlled by timeout counters. Also, each peer may decide to drop messages that are of no interest to it. Due to this dynamic self-management of the network, the need for message routing is reduced to those cases in which the peers can not directly exchange data that are of interest for them due to the terrain topology, the traffic situation or the radio propagation patterns. However, routing mechanisms are needed to provide a peer with the complete information about the others. Thus, we have defined two types of routing:

- Inter-Space Routing that refers to the routing of messages between peer spaces
- Intra-Space Routing that refers to the routing of messages between peers belonging to the same peer space

Due to the specific characteristics of the proposed zone-based organizations, the *inter-space routing* should usually not be employed. However, this routing may be needed for implementing services that require the delivery of information beyond the boundaries of a peer space. An example is the long-distance accident notifications. The applicability of this type of routing is limited by the communication features and the possible complexity of implementation. For example, when short-range communication is used, the lack of coverage between peer spaces can be a major problem. A solution lies in building an infrastructure that integrates a sufficient number of fixed peers for sustaining the communication between peer spaces. This solution may be applicable only in restricted areas due to the extent of the road network and the cost.

In the following we focus on the *intra-space routing*. The simplest solution for this type of routing is the flooding or the re-broadcast by each peer of the information received from other peers. This solution is highly inefficient [12] considering the bandwidth limitations and can lead to a serious overload of the vehicular communication. Therefore, we propose the use of mediation mechanisms, based on the characteristics of the peers that can directly communicate with each other. For this, all the peers include in the messages that contain the basic data the identities of the other peers that are known by senders to be registered in the same peer space. Further on, when a peer receives this information, it will add it to the records that describe the sender peers in its peer space database. The mediation mechanisms use these data as presented below.

Within the peer-centered organization, each peer is the organizer of its own peer space, whereas within the cluster-based organization all the peers organize together the peer space. Consequently, the mediation mechanisms are different for the two organization approaches. These mechanisms are also different for a vehicle peer and for a fixed peer since they have different traffic safety-related characteristics.

For the cluster-based organization we propose two methods: automatic and on-demand mediation. The automatic mediation means that any peer analyzes the records associated with the peers belonging to the same peer space and determines when a peer does not have data about another peer from the peer space. Since each peer includes in the exchanged messages data about the other peers that can communicate with, basic comparisons can be used for making these decisions. Further on, the peer that detects the lack of data will retransmit these missing data.

The on-demand mediation use similar comparisons but in this case each peer detects that it does not have data from another peer that was indicated by other peers as being part of the same peer space. Further on, this peer advertises a special message where it requests the missing data. When another peer that has the data receives the request, it will retransmit the needed information.

For the peer-centered organization we propose a basic automatic mediation. This type of routing is based exclusively on the ability of each peer to detect the importance of certain information for other peers and retransmit them. Thus, the mechanism is also based on comparisons of the peers' characteristics. For example, let us suppose that a peer P received two messages from two different peers and decides that these should belong to its peer space. Let now suppose that these peers do not have data about each other. Further on, the peer P analyzes the characteristics of the two senders and determines that they may be of interest for each other. Basic analysis such as the relative distance between the peers (e.g. less than 300 m) or more complex analysis can be used for making these decisions. Then, the peer P will retransmit the messages that characterize the two senders. An example of the mediation mechanism is presented in figure 6 where the vehicles V1, V2 and V3 are equipped with vehicular communication whereas the truck T is not. Also, the truck hinders the communication between V1 and V3. Then, V2 may detect that V1 and V3 can be interested in each other's data and retransmits this information.

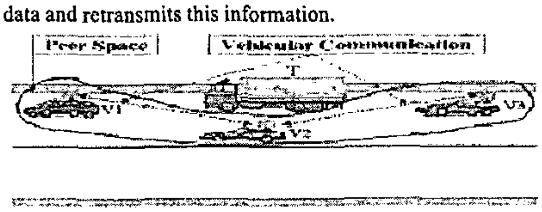

Fig 6. Intra-space routing

D. Peer-centered vs. Cluster Organization

The peer-centered organization differs from the cluster organization in that it considers c peer as the core of a group and organizes the vehicular network according to the peer singular interest. Thus, this approach is more appropriate for zones in which the vicinity awareness can be more stringent such as urban roads, whereas the cluster organization is more appropriate for highways.

Another difference is that, in comparison with the peer-centered organization, within the cluster organization the vehicles situated at the peer space borders received only limited benefit from data sent by peers that are part of other adjacent peer spaces. Improvements to this problem are the multiple membership and the inter-space routing. Another possibility is to allow a peer to consider very important warnings that are sent by peers not belonging to the same peer space. However, issues related with processing overload and false alarms need then to be addressed.

Further on, the peer-centered approach eases the establishment and maintenance of peer spaces and requires a simpler communication protocol in comparison with the cluster-based organization. Nevertheless, due to the overlapping between peer spaces, the peer-centered approach needs on average, more processing and storage capabilities per traffic segment than the cluster approach. It also requires more complex analysis for performing intra-space routing and does not support well the multicast communication that can be easily integrated within the cluster organization.

Both methods are flexible and scalable and provide a decrease in the number of retransmissions. This can be more extensive for the peer-centered organization, especially if an efficient intra-space routing is employed.

IV. RELATED WORKS

Complex infrastructure [5][6] and protocols using them [10] have been proposed for vehicular communication. Telematic services that are server oriented and are based on cellular communication are also currently under consideration. We have considered another alternative and propose a vehicular communication based on ad-hoc connectivity that is not dependent on an infrastructure. We have also merged IVC with VRC and consider the utilization of different short-range communication techniques. All of these can lead to a scalable, extensible and ubiquitous vehicular network.

Previously proposals for the organization of vehicular network are based on positioning data [12]. In our proposal we have introduced, alongside the positioning data, other information that characterizes the driving situation. This may lead to a more efficient organization and an increase of the situation awareness within the vehicular network. Thus, we proposed two zone-based organization methodologies and according with these we defined specific mechanisms for data broadcasts that differ from other approaches such as [9].

The mobile P2P approach has been proposed for supporting proximity-based impromptu applications [16]. We adapted the concept to the traffic environment and designed a specific communication. Further on, we have defined specific data processing and organization with regard mainly to safety but also other characteristics of the traffic environment.

V. LIMITATIONS AND CONCLUSION

We have defined basic rule-based mechanisms for the selection of the peer space by a peer. More advanced adaptive decision algorithms may be needed in order to provide extensive support for traffic safety. These decision methodologies may even need to be application-dependent.

The draft specification of the communication protocol has been produced and a platform for supporting the communication [17], which contain basic services, is currently under implementation. Simulations and field tests are subjects to future works and may result in modifications of the communication protocol and the decision algorithms.

To summarize, this paper proposes a safety-oriented vehicular communication that integrates the ad-hoc mobile P2P concept and short-range communication. This communication is designed considering specific requirements of the traffic environment and is characterized by independence from any infrastructure, ubiquity, resources and services sharing, self organization and possible cost efficiency.

These features recommend the proposed vehicular communication as an effective methodology for supporting the exchange of safety-related data within the vehicular network.

REFERENCES

[1] Bishop R., "Intelligent Vehicle Application world-wide", IEEE Intelligent Systems, vol. 15, pp. 78-83, Jan./Feb. 2000

[2] Jones W. D., "Keeping cars from crashing", IEEE Spectrum, vol. 38, pp. 40-45, Sep. 2001

[3] International Road Traffic and Accident Database (IRTAD), "Road Traffic Data" and "Accident Traffic Data", June 2001

[4] European Transport Safety Council (ETSC), "Intelligent Transportation Systems and Road Safety Report", 1999, Brussels, Belgium

[5] Intelligent Transportation Systems (ITS) America, "IVI Candidate User Services", 2001

[6] Advanced Cruise-Assist Highway System Research Association (AHSRA) Japan, "Primary Requirement of Advanced Cruise-Assist Highway Systems", 2001

[7] Aoki M., "Inter-vehicle communication: technical issues on vehicle control application", IEEE Communication Magazine, vol. 34, pp. 90-93, Oct. 1996

[8] Feeney L.M., Ahlgren B., Westerlund A., "Spontaneous networking: an application-oriented approach to ad-hoc networking", IEEE Communication Magazine, vol. 39, pp. 176-181, Jun. 2001

[9] Matsuda S., Koike H., Okada H., "Vehicular information broadcasting relay (VIBROR) protocol for inter-vehicle communication", Vehicular Technology Conference VTC2000- Fall, Boston, USA, pp. 2050-2010, Sep. 2000

[10] Widodo A., Hasegawa T., "Evaluations of traffic safety improvement using an autonomous traffic flow simulator including inter-vehicle communication", Global Telecommunications Conference, GLOBECOM, Sydney, Australia, pp. 2629-2633, Nov. 1998.

[11] Widodo A., Hasegawa T., "Impacts of environment adaptive running with and without IVCN", Vehicular Technology Conference Proceedings, VTC 2000-Spring, Tokyo, Japan, pp. 327-330, May 2000

[12] Sun M-T, Feng W-C, Lai T-H, Yamada K., Okada H., Fujimura K., "GPS-based message broadcast for adaptive inter-vehicle communications", Vehicular Technology Conference VTC2000- Fall, Boston, USA, pp. 2685-2692, Sep. 2000

[13] Morioka Y., Sota T., Nakagawa M., "An anti-car collision system using GPS and 5.8 GHz inter-vehicle communication at an off-sight intersection, "Vehicular Technology Conference VTC2000- Fall, Boston, USA, pp. 2019 – 2024, Sep. 2000

[14] Michael L.B., Kikuchi S., Adachi T., Nakagawa M., "Combined cellular/direct method of inter-vehicle communication", Intelligent Vehicles Symposium, Dearborn, USA, pp. 534-538, Oct. 2000

[15] Gong L., "Project JXTA: a technology overview", Sun Microsystems, April 2001

[16] Kortuem G., Schneider J., Preuitt, Thomson T.G., Fickas S., Segall Z., "When peer-to-peer comes face-to-face: collaborative peer-to-peer computing in mobile ad-hoc networks", International Conference on peer-to-peer computing, Linköping, Sweden, pp. 75-91, Sep. 2001

[17] Chisalita I, Shahmehri N., "A novel architecture for supporting vehicular communication", Vehicular Technology Conference VTC 2002, Vancouver, Canada, in press