Sensor Inter-vehicle Communication for Safer Highways

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Abstract

In this paper we present a sensor inter-vehicle communication protocol based on geographical routing. Sensors installed in cars continuously gather important information about: air bags, distance detection, mechanical and electronic parts, tire pressure, collision force, direction of impact and the car and its passengers' conditions. Our proposed protocol enables transmission of these information on point-to-point communications between cars in highway. The protocol is designed for highway travelers but can be used in any mobile ad-hoc network. The highway is divided in virtual cells, which moves as the vehicles moves. The cell members choose a center that will behave for a certain time interval as a Base Station. Every node has its geographical position given by Global Positioning System (GPS). When a source node has a message for a destination node, forwards it to its Cell Center. Then the message is forwarded through the other Cell Centers. The Cell Centers first verifies if the destination node belongs to their cell. Finally the destination Cell Center will send the message to the destination node. Our simulation results show that our proposed protocol improves the network utilization compared to existing inter-vehicles protocols. The protocol can be used to implement differentiated mobile services and message prioritization. Through simulation evaluations, we show that our protocol is very scalable and reduces the latency compared existing solutions.

1. Introduction

Wireless Sensor Networks (WSN), supported by recent technological advances in low power wireless communications along with silicon integration of various functionalities such as sensing, communications, intelligence and actuations are emerging as a critically important disruptive computer class based on a new platform, networking structure and interface that enable novel, low cost, high volume applications [2, 1, 7, 11]. One very promising application of sensor networks is in transportation systems.

One important goal in transportation systems is to reduce the dramatically high number accidents and their most of the time fatal consequences. To reach this goal automobile industry is working to equip cars with complex sensor arrays that continuously gather information about various systems including: air bags, distance detection, mechanical and electronic parts, tire pressure, and collision events. In the next few years, far more data, including information on the force, direction of impact and the car and its passengers' conditions will also be available. The information gathered by such sensors can be used to prevent accidents or determine the severity of accidents after they happen. In Fig. 1 is shown the sensor system used to gather important data about the car safety [5].

Existing communication systems send such information about car safety to calling centers that notify police about the accident location. Already there are close to 4 millions cars connected using OnStar, one of such systems in US [5].

It is paramount to be able to forward this important information related to car condition, as soon as possible to directly to police and emergency centers, who can make necessary emergency response and medical treatment decisions very fast.

One solution for such car safety communication is to use inter-vehicle ad-hoc protocols. Due to their intrinsic characteristic of no infrastructure, ad-hoc wireless networks provide for maximum of mobility. To meet the goals of such systems, provisioning of Quality-of-Service (QoS) within the wireless network system is a critical requirement.

Routing protocols are a critical part of ad-hoc wireless network architecture. In this case routing becomes much more complicated than in fixed networks, because of the absence of a fixed infrastructure. Here, the nodes rely on

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each other to forward packets toward the destination. Consequently the latency and bandwidth use increase compared to fixed networks.

One important goal in the design of routing protocols for ad-hoc networks is to increase their scalability. In Zone Routing Protocol (ZRP)[28] the scalability is improved by portioning the network in zones. This protocol applies a proactive routing protocol inside the zone, a modified distance-vector algorithm, and a reactive one outside the zone. There are also a few other protocols that incorporate *physical layer* information, such as received signal strength or geographic position into the routing algorithm [21].

In SICOMM we enhance and improve the idea presented in [21] in order to suit the protocol to the highway communications. SICOMM is based on a partition of the highway in cells, with optimal length that would make possible to control the number of hops participating in one communication. We also introduce a hierarchical scheme that would improve the QoS in inter-vehicle communications, making possible the diversity of services for different nodes, service prioritization and real-time communication.

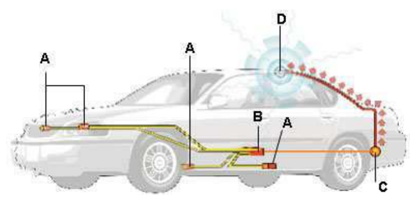

Figure 1. Sensor safety system gather information from sensors standard in many cars. Front and side impact sensors (A) detect crashes, while an interferometer (B) determines crash severity. The data is transmitted by a communication module (C) through an antenna (D)

2. Inter-Vehicle Communication Protocols

The main purpose of the Next generation ITS is the safe driving, which is represented by the developments of Advanced Vehicle Control and Safety System (AVCSS)[13]. The goal of the AVCSS is to improve the safety and convenience of driving, optimize energy consumption by having smooth traffic flow and increase the efficiency of transport industry. Other applications of ITS such as Advanced Traffic Management Systems (ATMS) [4] and Advanced Traveler Information Systems (ATIS)[9] are going to have new developments in the future. In order to design more efficient and safe transportation systems it is very important the design of efficient and safe inter-vehicle communication protocols.

Vehicle Information and Communications System (VICS)[16] enables a direct communication link between vehicles. In this case every vehicle receives the necessary information from the VICS center by using the preinstalled infrastructure. As the information is collected by the center, it is much more easier to deduce the road information, but the installation of such infrastructure is expensive and time consuming.

A more flexible way of communication is the Inter-Vehicle Communications (IVC)[16], where the vehicles are part of an ad-hoc wireless network and no permanent infrastructure is needed. There are significant differences between IVC and ad-hoc networks related to the nature of node movements, vehicle mobility, which is higher than in traditional ad-hoc networks and the movement direction. As the vehicles move along the road, the propagation of the information should follow the same one-dimensional movement. Another difference is related to the fact that in case of IVC all vehicles are moving and their relative speed with respect to each other is very small, resulting in stable wireless links between vehicles.

Most IVC protocols use flooding as the simplest way to broadcast. Flooding performs relatively well for a limited small number of nodes, but the performance drops quickly as the number of nodes increases. As each node receives and broadcasts the message almost at the same time, this causes contentions and collisions, broadcast storms and high bandwidth consumption [17].

Recently, a number of research groups have proposed more efficient broadcasting techniques. Centralized broadcasting schemes are presented in [3, 8, 9]. Algorithms in [15, 20, 22] utilize neighborhood information to reduce redundant messages in a Mobile Ad Hoc Network. Schemes in [10, 25, 12] deal with disseminating data in sensor netowks.

Source Based Algorithm [18], Dominant Pruning [15], Multipoint Relaying [20], Ad Hoc Broadcast Protocol [19], Lightweight and Efficient Network-Wide Broadcast Protocol [22] utilize two-hop neighbor knowledge to reduce number of transmissions. But in large scale sensor networks, especially with high densities, the two-hop neighbor knowledge might impose very high memory overhead. A good classification and comparison of most of the proposed protocols is presented in [26].

Several data dissemination protocols [10, 25, 12] have been proposed for sensor networks to disseminate data to interested sensors rather than all sensors. A broadcast protocol is presented in [6] for regular grid-like sensor networks.

Dedicated Omni-purpose inter-vehicle communication Linkage Protocol for HIghway automatioN (DOLPHIN)[13] is an example of IVC. In this case

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selective flooding is used to disseminate the information in the reverse direction of vehicle movement. The nodes that broadcast the information are reselected in every communication hop, being in the rear position of the previous one. This protocol is designed for cooperative driving and it would not have a good performance for other cases, such as point-to-point communications.

Another recent Inter-Vehicle communications protocol is the GPS-based Message Broadcasting [16] that uses a better broadcasting system, similar to the single cast routing protocol Zone Routing Protocol (ZRP) and performs much better than flooding based ones, but it still has routing overhead as long as the forwarding nodes are selected in every hop. It is a broadcasting protocol, and it would not be efficient for point-to-point communications.

In this paper we propose a new very scalable protocol, which needs minimal neighbor-hood information. Our solution provides QoS in inter-vehicle communications, making possible the diversity of services for different nodes, service prioritization and real-time communication.

3. Proposed Protocol

3.1. General Description

Existing routing protocols, where each node is required to select the next one or to continue route discovery, result in high delays in reaching the destination. Consequently this type of protocols, most of them based on flooding would not have the appropriate performance for point-to-point communications where each vehicle has a specific request, with different priority and different deadline.

In order to enable the above mentioned services and improve the Quality of Service in Inter-vehicle Communications, we propose a new protocol SICOMM that is based on Geographical Routing. We assume that vehicles are moving in the same direction and in the same highway, each vehicle knows its position and the destination's position by using GPS, vehicles have fixed optimal power for transreceivers, links are symmetric, and there exists a medium access control (MAC) protocol such that each node can transmit without interference.

We assume that the highway is divided into virtual cells, having the same equal optimal length that would depend on the MAC layer protocol used, length that would allow optimum transmission and reception. For better distributed network load, this number would be related to the average number of vehicles in each cell that depends on the average vehicle density for a given highway. As considered in [4, 14, 24, 28], a good choice would be IEEE802.11, and in such conditions a good cell length would be between $350-400$m. This cell range depends on the transmission power in 802.11 and is a good trade off between the fine-grained and coarse-grained distribution of information.

For each cell, the Center is positioned approximately in the middle of the cell. This position optimizes the communication inside the cell and with the neighbor cells. The Cell Center is selected from all other vehicles included in the same cell, and its position is updated periodically, and known by all members of the cell. When the Cell Center vehicle changes its speed and is about to leave the cell, it does a broadcast to all other members, so that they chose another Cell Center. The Cell Centers set represent a virtual infrastructure for the highway, which makes possible to have a 2 layer hierarchy routing [13, 27] with benefits such as better QoS for point-to-point and broadcast communications. We denote the Cell Centers as BS because they represent virtual Base Stations

When a source node S_i has a packet for the destination D_j, it checks if it can communicate directly with the destination, having it in the routing table after exchanging the hello messages. In case this is not possible S_i sends the message initially to its cell center BS_i, (previous BS_{i-1}, or next BS_{i+1}, whichever one is closest to the destination). The message is then forwarded between BS's until it reaches the destination BS_j, which send the message to the destination D_j. We use a mixed structure similar to cellular/Ad-hoc system as it is proven [23] that this gives better performance.

The routing table for every BS_i includes: the node ID and the node position in the respective cell; the node ID and the position of the next Cell Center BS_{i+1}, the node ID and the position of previous Cell Center BS_{i-1}. After receiving the message and before making a decision to further forward, each BSi does a check with its routing table to see if the destination vehicle is included in its cell. If the destination is there, it forwards the packet to the destination, otherwise to the next BS_{i+1}, which repeats the same procedure. In a minimum number of hops the destination node receives the message. This number would be $(L+2)$, where L is the number of hops and 2 stays for: source to first Cell Center communication and last Cell Center to destination communication.

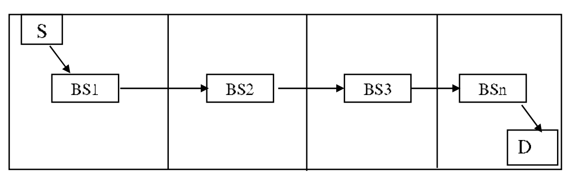

Figure 2. Forwarding schematics using virtual Cell Centers

SICOMM has low routing overhead, as cell membership update is done during position update for each cell, and is a maintenance feature. During the source to destination communication the Cell Centers positions are already known. Even when the node that is currently the Cell Center has to leave the cell, it broadcast the message to the cell members, which start selecting a new Cell Center. Due to small relative mobility between the cars, the update process of cell membership can be done much less frequently than the position update process, making this virtual infrastructure relatively stable. However during each update of node positions, the cell memberships are updated too, as this is included in their hello messages, and the Cell Center BS_i broadcasts its position to its members and to the neighboring Cell Centers, BS_{i-1} and BS_{i+1}.

The advantages of SICOMM algorithm compared to flooding based ones are:

- Eliminates the negative effect of broadcast storms by creating a hierarchical message forwarding scheme.
- Makes possible to incorporate a specific scheduler at Cell Centers, that would allow a differentiated Service for different nodes.
- Makes possible to create a group sharing communication (for example all cars that are members of the same group).
- Is much less expensive than flooding, as the total number of messages exchanged for every communication is much smaller.

3.2. Algorithm Description

Cell Creation:

Each car takes from GPS its current geographical position $pos(x, y)$ and its current speed. The cells, which are in radio communication range exchange Hello messages among themselves. The first car that cannot reach other cars ahead, broadcasts its position, which is considered the first $Cell_1$ border for that Highway in order to start the process of creating the virtual infrastructure, which takes two steps: Cell Numbering process and Cell Centers' selection process.

All nodes establish their respective Cell Membership, knowing that they have a distance that is a multiple of $400m$ from the node that declared the borders. Lets denote the first Cell border coordinates as (Xo, Yo). Simultaneously, in every cell, each node exchanges *Hello messages*, including: first node coordinates, current node position, current speed, current cell number. The current Cell Number is calculated as:

$$Cell\_number = \left\lfloor \frac{D}{400} \right\rfloor$$

$$D = mod400\sqrt{(my\_X - Xo)^2 + (my\_Y - Yo)^2}$$

where *D* is the Euclidian distance between the node with coordinates (my_X, my_Y) and the first Cell border. For a better performance, *Hello messages* are exchanged also between adjacent nodes that belong to neighbor cells. Using this feature, these adjacent cells can communicate directly without going first through their Cell Centers.

Members of the same Cell participate in the process of selecting the respective Cell Center. After that the Cell Center broadcasts its coordinates to all cell members and to immediate Cell Center's neighbors.(BS_{i-1} and BS_{i+1}).

Cell-center selection: Every node in every cell knows the ideal Cell Range and the ideal Cell Center coordinates (XC_i, YC_i). If the distance d_i from a given cell to its ideal Cell Center is less than an agreed value d_0, this cell considers itself the Cell Center and broadcasts the message "I am the Cell center candidate with $d = d_i$". The candidate with smallest d sorts the results in increasing order and broadcast its positions with a respective timestamp. If after a certain interval the Cell center is not yet advertised, the process restarts with $2d_0$ (loop while) and so on until it will be selected a Cell Center, even if there is only one car in this cell.

Update and maintenance process: After being selected, a Cell Center broadcasts its ID, Coordinates, and ID and coordinates of both sides adjacent Cell Centers. Each cell updates its cell membership in the Hello messages with the others.

3.3. Point-to-point communication algorithm

If node Source $S(X_s, Y_s)$ has a message for node destination (X_d, Y_d), for example the destination could be a First Aid Health Center or an Emergency Station the following algorithm will be applied (illustrated in Fig.2):

1. The source node included in the Cell i:
    - Checks the direct communication option with the destination if the distance:

      $$d = \sqrt{(X_d - X_s)^2 + (Y_d - Y_s)^2}$$

    - Otherwise it forwards the message to its own Cell Center BS_i:
2. After receiving this message the cell center BS_i, forwards it to the $BS(X\_bs, Y\_bs)$, which is closer to the destination. The closer BS to destination will have the minimal distance to destination (d_BS_min) calculated as

   $$d\_BS\_min = min\sqrt{(X_{bs} - X_d)^2 + (Y_{bs} - Y_d)^2}$$

3. After receiving a new message a center BS, first checks in its routing table if the destination is a member of this cell. If not it continues the forwarding process to the other Centers applying the same algorithm as in step 2 for selecting the Next Cell Center that would continue to forward the message toward the destination.

4. Simulation Results

4.1. Assumptions and simulation model

In our simulations we assume a channel bandwidth of 2Mbits/s, which is similar to the rate obtained by using IEEE 802.11. A link is characterized as an FCFS queue with service time as the propagation time. We are focused to network layer details. We used a simple workload model where all data packets are 512 bytes long.

We consider three kinds of channels:

1. Hello-exchange channels between all nodes in the radio range of ∼600m.

2. Center-Channels between all nodes of a cell and their respective center.

3. Cell-to-cell Channels between sequential Centers.

We assume symmetric channels. We have done simulations with 15 and 30 nodes network.

4.2. Simulations results and performance analysis

To evaluate the protocol performance we consider the following two metrics:

End-to-end delay, measured in ms. This is given for conversations between different sources and destinations picked randomly and having different distance from each other. **Routing load**, measured in terms of number of messages transmitted for every communication source to destination.

We have compared our protocol with DOLPHIN [13]. As showed in the Fig. 3, we compare the end-to-end delay (Y-axis) for different communications between nodes with distance given by X-axis For close cars, both SICOMM and DOLPHIN perform almost the same. As we see the source to destination delay is ∼ 5ms. For more distant cars, SICOMM performs much better introducing smaller end-to-end delay than DOLPHIN. This is explained by the use of a version of selective flooding for DOLPHIN, where every node broadcasts the message to the other nodes behind it and this process continues sequentially.

For the same scenario, we have compared the total number of messages exchanged or routing load, during every source to destination communication for both protocols.

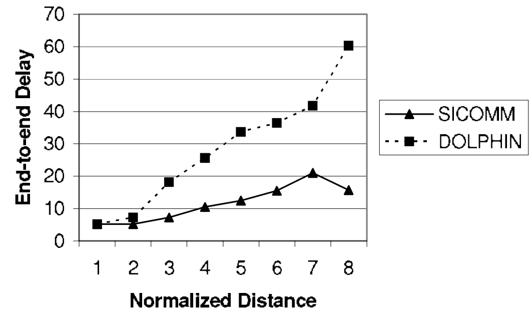

Figure 3. Comparing end-to-end delay between SICOMM and DOLPHIN. The distance is multiple of 100m

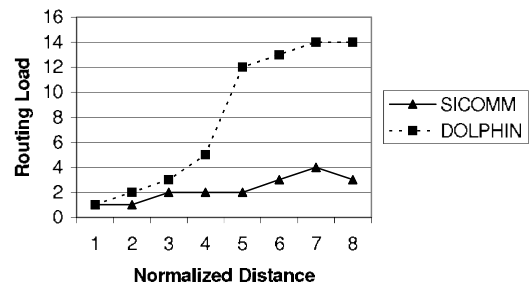

Figure 4. Comparing the Routing Load between SICOMM and DOLPHIN. The distance is multiple of 100m

The results presented in Fig. 4 show that SICOMM has much smaller routing load than the other one. This is explained by the fact that by using a hierarchical scheme the number of messages to be exchanged would be the same as the number of cells between the source and the destination plus two (one communication between the source node and its closest Cell Center and the last Cell Center to the destination). The number of messages exchanged during DOLPHIN is much higher because during the selective flooding the number of exchanged messages grows very fast as the number of nodes participating in every communications grows very fast , so for nodes being more than 400m far away the number of exchanged messages if 14, while by using the geographical Routing this number is only 3.

From these results it is clear the advantage of SICOMM especially for distant communications.

5. Conclusion

We presented a new Sensor Inter-vehicle Communications protocol SICOMM based geographical routing in a partitioned highway. SICOMM outperforms similar flooding based routing protocols in end-to-end delay and routing overhead. The hierarchy scheme used makes possible the implementation of different distributed policies, giving a differentiated service and improved QoS. SICOMM makes possible a real time communication between distant vehicles, and Group Members Vehicles.

We plan to continue this work by implementing in Cell Centers a real-time scheduler and develop differentiated services. Also we plan to develop a traffic simulator interface and study the behavior of mobile nodes.

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