Inter-Vehicular Communication Systems

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Abstract. Driver assistance systems are meant to support drivers with driving process in order to avoid traffic accidents, speed up the traffic and have a higher control over the traffic in general. There are a lot of systems which give support to the drivers, such as adaptive cruise control, traffic sign recognition, automatic parking, etc. In this paper we focus on the vehicular communication systems. These systems use the capacity of the vehicles to communicate, not only between them but also with infrastructures. All the information is collected and processed to offer useful services. Wireless Sensor Networks (WSN) are widely used in this area. With the incoming upgrades of these networks, they are becoming an attractive solution to give support with the communication mechanisms between vehicles.

Keywords: ad hoc networks, wireless sensor networks, inter-vehicular communication, protocol.

1 Introduction

Recent studies shows that about 60% of roadway accidents could be avoided if the driver was warned just one-half second before the collision occurs. Actually, traffic accidents have become the main cause of mortality, quite above illnesses. Emerging technologies appears to provide faster, safer and more reliable communication techniques. Bring together, this communication can be used in order to reduce collisions, as well as to support and improve the quality of the traffic. There are different kinds of systems to assist drivers in the roads. This paper is focused on the inter-vehicular communication (IVC). IVC has attracted research attention from the transport industry of Japan, EU and US. Within this area there are also a lot of different services that can be provided, and different strategies to implement them. The main goal of IVC is to upgrade on-board devices (i.e. GPS, sensors) and, thus, to extend the horizon of drivers. IVC applications can be categorized in three main groups. Cooperative assistance systems focus on coordinate the vehicles in critical points like junctions with no traffic lights. Communication-based longitudinal control tries to exploit the look-through capability of IVC to reduce accidents and platooning vehicles to increase the capacity of the road, while information and warning functions give support with real-time warning messages to avoid collisions. A protocol from this last group is presented in this paper as an example of IVC.

The communication can also be categorized as follows. When the communication occurs between vehicles, it is called Vehicle-to-Vehicle (V2V) communication. It takes place in cooperative driver assistance or in decentralized floating car data sharing (i. e. traffic monitoring). If the communication is between a vehicle and a infrastructure, that is, Vehicle-to-infrastructure (V2I) communication, then vehicles can communicate using a fix infrastructure along the road to give support some services like Internet access, inter-vehicle chat, mobile advertising…etc.

A number of projects are based on IVC technologies. The most important are named and briefly described as follows. FleetNet is project whose goal is to provide Internet to vehicles. Wireless Local Danger Warning (WILLWARN) is minded to prevent accidents. Car2Car is a consortium of six European car manufacturers. It focuses on the V2V communication and it is based on wireless LAN. It aim is to establish an open European standard. The main purpose of Network on Wheels (NOW project) is to solve problems related to data security and communication protocols. Finally is worth to mention CHAUFFEUR project. This project offers an optimal way to use the roadways. The idea here is that a leading car driven by a human sends information to a group of followers, which repeat exactly the same the driver-pattern conduct of the leading car. This is called 'platooning' of vehicles. Not only does it make a better use of the roadway capacity, but it also saves power as the group become aerodynamic. Most of these projects use the standard IEEE 802.11 for communication. But also GSM, UMTS, GPRS protocols are used in some of these projects. [1][2][4]

After this short introduction, the rest of the paper is organized as follows: First, specific requirements for this system are presented in Section 2. Secondly the characteristics of the network topology are addressed in section 3. Then an overview through the basic networks layer is described in section 4. Finally, a protocol to deal with traffic collisions avoidance is presented in section 5. The paper ends with the conclusions in section 6.

2 Requirements

Availability, reliability, safety, integrity and security are among the main requirements for IVC systems. However wireless communication is typically unreliable due to packet collisions, channel fading, shadowing and the Doppler shifts caused by the high speed of vehicles. It is then a big challenge to deal with sensor nodes that travel at a high speed.

Fig. 1. The critical latency requirement. [2].

The latency requirement can be critical, because of the high speed of the vehicles. In figure 1, we have the typical collision scenario where A and B are driving at 180 Km/h. Then A sees an obstacle and decides to break. In this case, IVC systems must support a warning mechanism that warns B with enough time to stop in time.

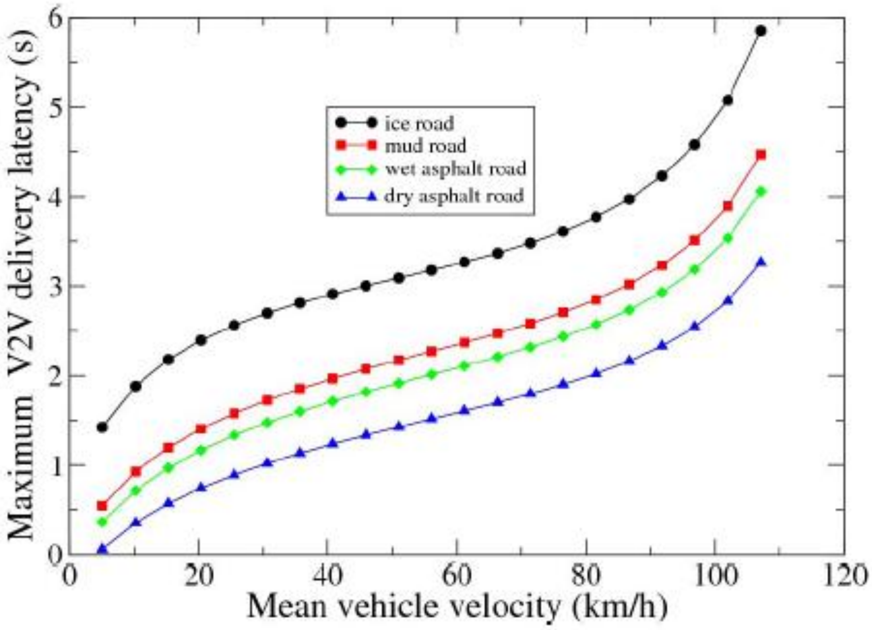

Fig. 2. Allowed delivery latency for V2V communication.

Precise mathematic calculations have been made in [7] to show the graphic in Figure 2. Here we can see that the latency requirement grows exponentially as the vehicle move faster.

Security requirements are also important. A vehicle could transmit false warnings, in order to show up as an emergency vehicle. Also, messages can be used to track a vehicle and get private information about the driver and passengers. Security mechanisms such as authentication, integrity and privacy protection must be supported.

The IVC networks must also support scalability. The network can become dense in a very short time, if a lot of vehicles get stuck in a traffic jam. [1][2][5]

3 Topology.

The linear nature of most IVC systems present a particular distribution of the nodes. Linear sensor networks is a new area of research which can optimize the inter-vehicular communication. In these networks, nodes appear aligned in a linear formation that characterizes the topology in IVC networks.

Fig 3. Linear nature of IVC. [1]

In figure 1 is shown a V2I typical nodes distribution. A1 and A2 nodes acts as gateways to infrastructure networks such as the Internet, a control center or other backbone network depending on the application that is going to be used.

However, not always the topology is purely linear, since a highway usually have more than one lane.[1][5]

4 Basic layers.

Routing inside a low power area network (LoWPAN) might be a challenge, as the RPL has to work over lossy radio links, with battery-powered nodes, multihop mesh topologies and frecuent topology changes.

To give a solution several working groups are giving support to the RFC's for this protocol. One of them is the routing over lowpan and lossy networks (ROLL) who is in charge of routing tasks. Meanwhile the 6LoWPAN is trying to bring the new IPv6 addressing system to these resource-constrained devices.

4.1 MAC/PHY layer.

Radio waves and infrared have been studied to give medium support to IVCs. The radio waves include micro, millimeter and VHF waves. The communication with millimeter waves and infrared are usually directional, while VHF is used for broadcast. The typical radio bandwidth used in IVC is 5.9 GHz in US, 5.8 GHz in Japan and 5.8 GHz in Europe.

The FleetNet project chose ULTRA TDD due to the availability of the unlicensed frequency band 2010-2020 MHz in Europe. Most projects, however, have adopted the use of infrared (CarTALK, COOPER, JSK, PAT H…).

There are two approaches in developing MAC for IVCs. One is using IEEE 802.11 as a radio interface, while the other consists on extended 3G technology, such as CDMA for distributed access. Both of them have to be modified and adapted to provide an efficient solution for IVCs. The advantage of using IEEE 802.11 is the inherited support for distributed coordination in ad hoc mode. On the other hand, 3G extensions present high granularity for data transmission.

4.2 Network layer.

Almost all routing protocols used by the different IVC projects are position-based. In addition, existing MAC ad hoc protocols could be directly applied. But if an optimal performance is desired taking into account the linear nature of the networks seen in section III, modification of the existing routing protocols must be performed.

In addition, the features most of vehicles offer nowadays makes possible to get position information via GPS or GIS, very useful for routing. The protocol in section VI uses a forwarding scheme which avoids beacons for improved efficiency.

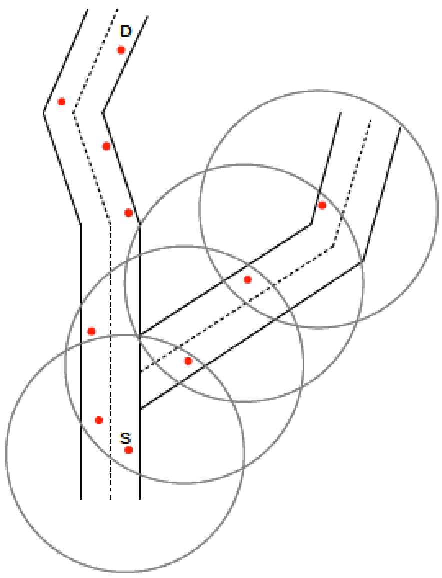

Fig 4. Position-based greedy forwarding leads into dead end. [5]

However, position-based routing protocol may derive some problems. This is shown in figure 4. Where a greedy forwarding based on the position of the destination is used for next hop calculation.

Although much research has been done in ad hoc routing, there are not still many solutions for the special demands of a vehicular network. [4][5]

5 The Vehicular Collision Warning Communication Protocol .

5.1 Introduction.

As mentioned in section 1, the reduction of traffic accidents can save a lot of human lives. The Vehicular Collision Warning Communication (VCWC) protocol presents a communication mechanism to warn vehicles when an abnormal situation occurs, so that they can stop before crashing.

This protocol uses the standard 802.11for the communication between vehicles. Due to the unreliable wireless communication, this protocol must provide this reliability by retransmitting packets that did not reach their destination because of collisions, or channel fading.

There are two different basic approaches to establish the way the vehicles will send warning messages. The passive approach makes vehicles to frequently broadcast their motion information. High precision vehicle positioning information is needed, along with a high refresh rate. In the active approach the message are only sent when a problem occurs, that is, when a vehicle acts abnormally. This protocol chooses the active approach because it causes much less traffic in the net.

As seen in section 2, the delay is a critical requirement. When an emergency occurs (i.e. strong change of direction, mechanical failure…) then the vehicle is referred as Abnormal Vehicle (AV). This vehicle must send an Emergency Warning Message (EWM) to let the surrounding cars know about this event. The delay of these EWMs must be in the order of milliseconds as shown in section 2.

5.2 Assumptions.

In this protocol it is assumed that every vehicle is equipped with a system which is able to get the geographical position of the vehicle. It is also assumed that the vehicle has a wireless transceiver. All vehicles use the same IEEE 802.11 standard and share a common channel.

The VCWC protocol does not require all vehicles to be able to send or receive these messages, since this protocol is also helpful when not all the vehicles have a transceiver. Even when the majority of vehicles do not count with this system, the VCWC protocol brings benefits to all vehicles.

5.3 Message differentiation.

The VCWC protocol uses different types of messages. As they have different priorities, the protocol must support a mechanism of differentiation between messages. Of course the messages with the highest priority are the EWMs, followed by the forwarded EWMs. The forwarded EWMs occur when a vehicle receive a EWM and must spread the warning alert to following vehicles. The third type of messages is the non-time-sensitive messages, with deal with control tasks, independent of events.

In order to perform this differentiation, the way 802.11 coordinates media access is analyzed. When a vehicle has a packet to transmit, it has to wait the channel to be idle during the Interframe Space (IFS). Then, a random backoff is selected to transmit. Different levels of priorities can be established using different IFS. For example, messages with high priority use a smaller IFS.

5.4 Congestion control of EWMs.

It is common that more than one AV coexists in time. For example, if a car stops in the highway due to a mechanical failure, it remains sending EWMs messages to approaching vehicles and will remain AV until it is retired from the road. Also, due to the natural chain effect that is produced in emergency events. The coexisting AVs might send messages at the same time, leading to packet collisions. The VCWC protocol has to deal with multiple AVs.

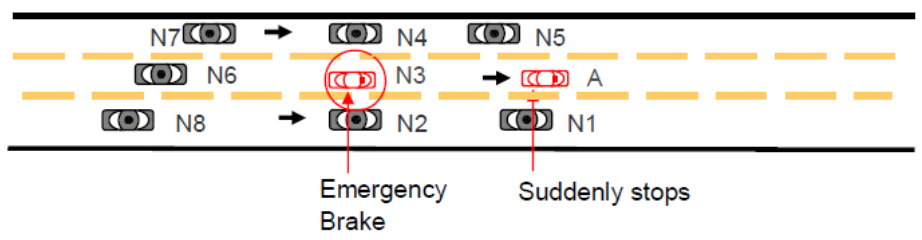

Fig. 5. Typical collision scenario. [2].

Another phenomenon might increase the congestion in the network. This is known as Redundant EWMs. In Figure 5 is shown an example of this. Vehicle A suddenly stop, N3 breaks because of A detention. In this case, the EWM sent by N3 and the EWM sent by A are actually warning about the same event.

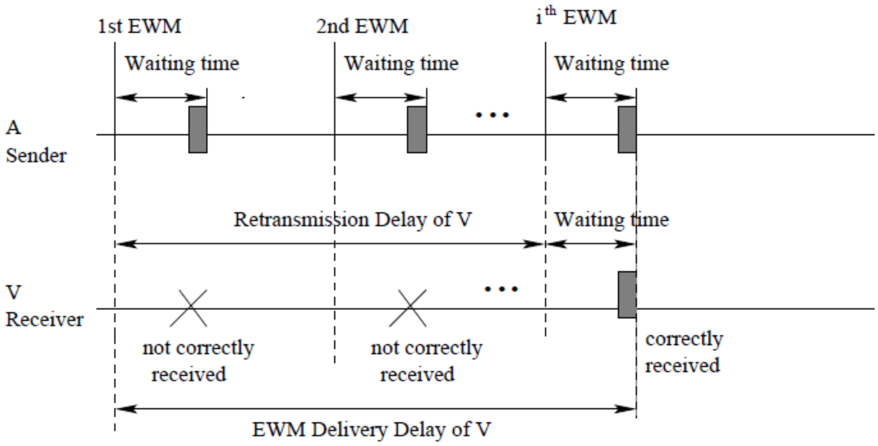

Fig. 6. Waiting Time and Retransmission Delay. [2]

To ensure a reliable communication over unreliable wireless channel, EWMs must be repeatedly sent at a certain rate. However, if the retransmission rate is too high, there are more EWM messages travelling in the same time which leads into a high congestion of the network. In addition, as an EWM cannot be transmitted until the previous has been transmitted, the inter-transmission duration of EWMs adds delay to the retransmission delay as shown in Figure 6.

$$Delay = Delay_{wait} + Delay_{retransmission} \qquad (1)$$

Figure 6 shows the total delay, described by equation 1. Hence, a high transmission rate would contribute to high congestion, increasing the waiting time (Delaywait).

In the other hand, a low transmission rate would increase the retransmission time (Delayretransmission). A good balance must be found. The strategy presented in the VCWC protocol takes into accounts the fact that at the beginning of an accident event the delay must be minimized.

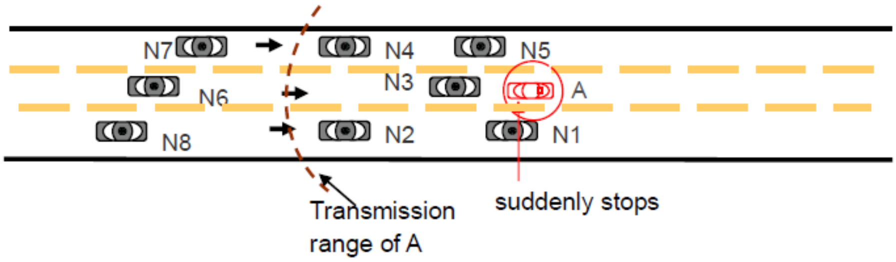

Fig. 7. Delay requirement relaxation. [2]

However, once the closer vehicles have been warned, the higher distance with the approaching cars allows a certain delay relaxation. This is shown in Figure 7, where A must quickly alerts N3, but can offer a bigger delay to warn N6. This relaxation delay allows the VCWC protocol to reduce the transmission rate, and consequently reduce the traffic congestion in the network.

For this purpose the Decreasing Algorithm for EWMs is presented. The main idea is to start with a high EWM transmission rate and use a multiplicative decrease. If the decrease is too slow, the traffic congestion might increase rapidly, with the consequent increase of the waiting time. On the contrary, if it is decreased too quickly, then the retransmission delay gets larger and larger.

Empirical experiments and mathematical analysis are executed in [2], to set a function which optimally decreases the transmission time. The equation is:

$$F(\lambda_0,k) = max\ (\lambda_{min},\ \lambda_0/a^{k/L}) \qquad (2)$$

Where λ_0 is the initial transmission rate, k is the number of the EWM to transmit, λ_{min} is the minimum transmission rate allowed, 'a' is a factor which optimal value according the mathematical analysis is a=2, and L is the number of transmitted EWMs so far.

5.4 State transitions of the AVs.

The main goal of the state transition mechanism is to guarantee EWM coverage avoiding redundant EWMs. Redundant EWMs was first addressed in section VI-D. An initial AV can enter the non-flagger AV state, if it becomes aware of another node sending the same alert. Non-flagger AVs do not send any EWMs.

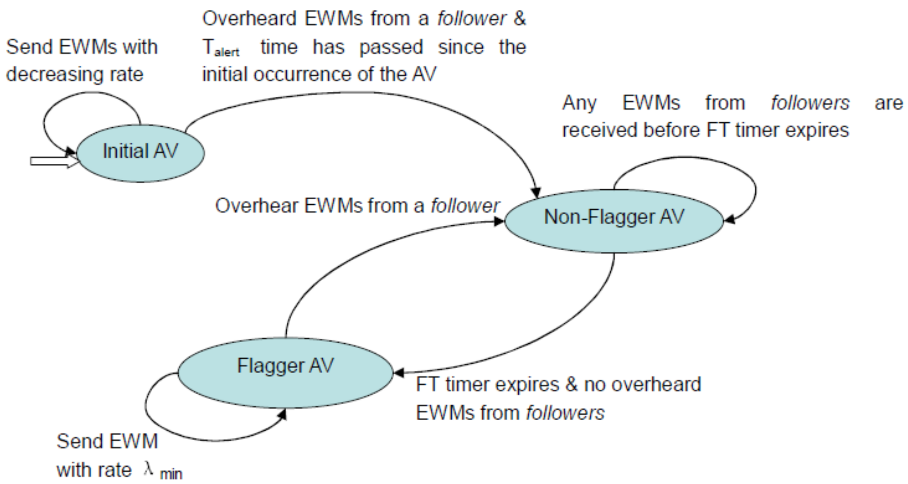

Fig 8. State transition diagram. [2]

When a vehicle becomes AV for some reason, it enters in the Initial AV state. Here the algorithm presented in section VI-D will decrease the transmission rate. In the Non-flagger state the node does not send any EWM, while in the Flagger state the node send EWMs at the minimum rate $\lambda_{min.}$

In order to retire redundant EWM and reduce traffic congestions, if a node receives an overheard EWM from a vehicle positioned behind right in the same lane (a follower), this node enter the Non-Flagger AV state and stop sending EWMs. Thanks to positioning systems (i.e. GPS) the vehicles are able to detect their followers according the above description of "follower".

All this process happens after a period of time that is denoted T_{alert} Within this period the node should have been able to send the EWM to the nearest vehicles which are in real danger.

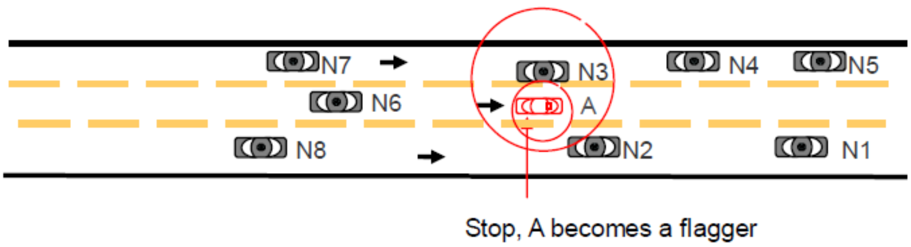

Fig. 9. Node A becomes non-flagger.

Such an example is shown in Figure 9, where node A stop transmitting EWMs as it becomes aware that N3 is also sending EWMs. After T_{alert} ,when A overheard EWMs from N3 enters the non-flagger state.

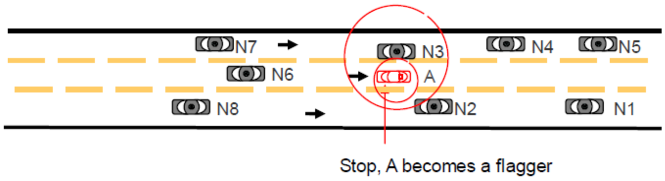

Fig. 10. Node A becomes flagger.

Following the example in Figure 9, it might happen that N3 stops forwarding EWMs from A. Suppose, for example, that N3 change of lane as shown in Figure 10. Then vehicle A should warn again possible affected vehicles like N6. For this purpose VCWC protocol make AV to switch between states of non-flagger and flagger AV. After Flagger Timeout (FT) expires, the node becomes Flagger if it stops receiving overheard EWMs.

Finally the reason to switch from flagger to non-flagger state is the same as when the AV is in the initial AV: Overheard EWMs are the key to detect redundancy and stop transmitting.

Sometimes, when a vehicle detects an AV ahead, it make breaks dramatically becoming itself an AV. This natural dissemination makes unnecessary for the VCWC protocol to implement an emergency forwarding mechanism.

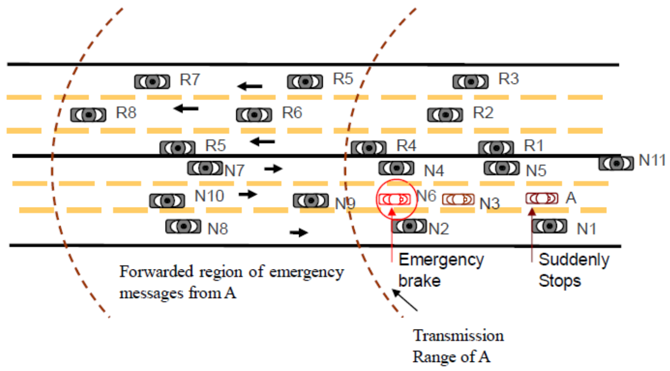

Fig. 11. Natural dissemination does not work.

There is a case where the natural dissemination would not occur. In this scenario, Figure 11, 'A' stops suddenly and N3 and N6 receive the corresponding EWM, but neither N3 nor N6 break strong enough to become an AV. Then N9 which is out of the communication range of the AV 'A' could have problems to stop in time since it is not aware of the abnormal behavior that caused the reaction of both N3 and N6.

However the probability is very low, as the breaks should become softer and softer as the vehicles are further of the original vehicle that originally stopped.

6 Conclusions.

IVC communication is an emerging area and important source of research thanks to the improvements of in-vehicle computing and processing capabilities and also the advancements in mobile and wireless communication.

Design a protocol for IVC is extremely challenging, since it has to deal with the high mobility of vehicles, and also offer a secure communication.

The VCWC protocol presented in this paper proposes an alternative to improve road safety. It manages to get a small EWM delivery delay and supports a large number of coexisting ANs. It also includes a system to discard redundant WEM, taking advantage of the natural chain effect of emergency events.

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