Disseminating Messages among Highly Mobile Hosts based on Inter-Vehicle Communication

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Abstract

We present an approach to distributing messages among highly mobile hosts in ad hoc networks. We focus on using direct radio communication between moving vehicles on the road that requires no additional infrastructure. Thus, the vehicles need to organize access to the radio channel in a decentralized manner. We derive the medium access control from the standard IEEE 802.11. Also, the vehicles use omnidirectional antennas implying that a sender can transmit to multiple hosts simultaneously. As an example, we study a road accident that is reported to nearby vehicles. Simulations show us the quality of the proposed protocol by measuring how many vehicles inside a zone-of-relevance are informed under various conditions.

1 Introduction

Recently, research in the area of inter-vehicle communication has mainly focused on applications of platooning [14, 5, 17]. Furthermore, research in vehicle-to-vehicle communication has concentrated on cooperative driving which requires enormous bandwidth and expensive equipment to achieve the desired reliability [13, 2]. Today, radio transmitters are becoming smaller and cheaper. Tests have shown a general feasibility of these receivers in inter-vehicle communication [16]. Although these receivers do not meet the requirements of safety critical applications like collision avoidance or automated driving, they can be used in less critical applications that provide improved comfort and additional safety.

Here, we present an approach to hazard warning in road traffic with a system based on inter-vehicle communication. The vehicles are equipped with a computer controlled radio modem allowing them to contact other equipped vehicles in their vicinity. The resulting ad hoc radio network requires no additional infrastructure at the road side. We also take advantage of the broadcasting nature of radio waves; a vehicle sending one data packet can reach multiple hosts simultaneously.

As an example of potentially dangerous traffic situations, an equipped vehicle identifies itself as crashed by vehicular sensors that detect events like airbag ignition. Then, it can report the accident instantly to nearby vehicles. We present an algorithm to disseminate such a message among the other equipped vehicles on the road. Multihopping allows us to enlarge the area in which a vehicle could receive the message. We introduce the concept of a zone-of-relevance that defines the area in which the message is relevant to the driver. We adopted the idea of a zone-of-relevance from Kassubek [9]. If the warning message reaches a vehicle which is inside a zone-of-relevance, the driver can be informed early by the system. Thus, we intend to help the driver cope with a potentially dangerous or inconvenient situation. Equipped vehicles outside the zone-of-relevance participate in passing the message but their drivers are not alerted to avoid unnecessary and hasty reactions.

2 Related Work

Novel studies have examined medium access control [19, 11, 20] and routing [3, 18, 4] in the context of mobile ad hoc networks. However, due to the high mobility of hosts in road traffic, our application resides close or beyond the worst case scenarios depicted in those papers. Also, we cannot simply apply the classic definition of routing packets from a source to a sink because the identities of the prospective receivers are a priori unknown. This problem also occurs in other mobile applications, so that Imielinski and Navas [7] and Ko and Vaidya [12] proposed the idea of using geographic constraints to specify the destination of a packet. The Location-Based Multicast (LBM) protocol described by Ko and Vaidya [12] works similar to our proposed multihopping algorithm. The region to which a so-called geocast should be delivered is named the "multicast region." A "forwarding zone" contains the multicast region and connects it to the source node. LBM differs from our algorithm in that LBM limits the multihopping process to nodes inside the forwarding zone whereas in our scheme potentially everybody participates in the dissemination process as long as a certain number of hops is not exceeded.

3 Proposed System

Every equipped vehicle performs the same protocol that consists of two layers: The medium access control (MAC) and the message passing algorithm.

The IEEE 802.11 standard [8] for wireless local area networks covers ad hoc networks lacking any fixed infrastructure. We use the standard and adopt its carrier sense multiple access (CSMA) strategy. When a packet is ready for sending, the MAC first senses the channel. If the channel is idle, the MAC layer will send the packet immediately. Otherwise, the system waits until the current transmission has finished to set a timer with a randomly chosen backoff time. When the timer expires, the MAC will send the packet. During the backoff period, the timer is halted when the MAC layer detects activity on the channel again.

If the system receives a packet successfully, it invokes the upper message passing layer. This layer handles a list of recently received messages to determine whether a message is unrecognized. Due to multihopping it is more likely to receive transmissions of the same message which have to be discarded. When accepting a packet from the underlying medium access control, the system discards known messages (i.e. messages that are part of the list) immediately. When it receives an unknown message, the vehicle adds it to its list and we name the vehicle "informed about this message." Then, the system forwards the message according to a multihopping strategy.

To understand our motivation for using a multihopping strategy rather than resending messages immediately consider the broadcasting nature of radio waves. Multiple hosts can receive the same packet simultaneously. Then, an immediate resending would cause burst-like traffic on the channel. It is well known that CSMA suffers from instability when the capacity of the channel is reached [10, 21]. Hence, we try to avoid peak load by forcing the receivers to wait by applying the following mechanism.

Assume that the packet header contains the position of its sender. Many vehicles already use navigation systems. Future global positioning systems will handle errors in range of meters [15] or better. By knowing its own position, a receiver determines the waiting time WT depending on the distance d to the sender such that the waiting time is shorter for more distant receivers as shown in equation 1. Thus, mainly hosts at the border of the reception area take part in forwarding the message quickly.

$$WT(d) = -\frac{MaxWT}{Range} \cdot \hat{d} + MaxWT \qquad (1)$$

$$\hat{d} = \min\{d, Range\}$$

$$\text{where} \quad MaxWT : \text{maximum waiting time}$$

$$Range : \text{transmission range}$$

In applying ad hoc networks to inter-vehicle communication, the size of the resulting ad hoc network is potentially unbounded. Our aim in using the proposed system is to disseminate messages quickly and efficiently in a local area around the initiating vehicle. Thus, we prevent the packet from being forwarded infinitely by counting the number of hops that a packet performs. If the number exceeds a given threshold $MaxHops$ the system discards the packet.

4 Characteristics of Inter-Vehicle Radio Communication

To study our approach to message dissemination, we modeled the radio communication as follows. When they are within transmission range of a sending vehicle, all other equipped vehicles potentially receive the data packet. Having tested two radio modems operating in the 2.4 GHz industrial, scientific, and medical (ISM) band, we measured approximately 600 m as the maximum distance for receiving data.

Next, the transmission duration for one packet is derived from the packet length and the bandwidth of the radio channel. The tested radio modems achieved a bandwidth of 3.6 kBytes/s. We estimated the packet length including the position information to be 73 Bytes. Therefore, the computed duration of one transmission is 20 ms.

The well known problem in radio networks that lack full connectivity is packet loss due to hidden stations. Consider two senders A and B being out of range of each other but a receiver C sits in the middle of A and B hearing them both. Now, A and B may start transmitting a packet simultaneously because they both have sensed the channel idle before. In this case, the packets from A and B collide at the receiver C. To simulate this effect in our model, a station receiving packets from two different senders at the same time discards both packets.

Finally, we set the parameters of the message passing layer. The waiting time should be on average longer than the transmission duration. Therefore, we choose the maximum

description	value
transmission range (*Range*)	600 m
packet length	73 Bytes
bandwidth	3.6 kB/s
transmission duration	20 ms
maximum waiting time ($MaxWT$)	40 ms
maximum hops ($MaxHops$)	20
computation time	50 ms

Table 1: Parameters of inter-vehicle radio communication

description	divided highway	undivided highway
length of straight road	10 km	10 km
lanes in each direction	4	2
driving directions separated	yes	no
average velocity	130 km/h	70 km/h
traffic density	5 veh/km per lane	25 veh/km per lane

Table 2: Parameters of road traffic scenarios

waiting time to be twice as long as the transmission duration, hence to be 40 ms. The dissemination of the message is also ultimately controlled by the maximum hops it can take. We limit the propagation of a message to 20 hops. Also, we assume that the system needs a constant computation time of 50 ms to process the multihopping algorithm. Table 1 summarizes the parameters of the inter-vehicle radio communication introduced in this section.

5 Scenarios of Road Traffic with an Accident

As an example application of our approach, we demonstrate the equipped vehicles distributing a warning message about an accident in road traffic. We model a straight road 10 km long. The accident happens in the middle of the simulated stretch. Two different road types are considered: a divided highway and a highway without divider. When measuring the quality of message dissemination, we focus on a zone-of-relevance that defines the area in which drivers should be informed about the accident.

For the road model of the divided highway, the zone-of-relevance covers the region behind the accident on the side of the highway where the accident happens. The divided highway consists of four lanes in each direction. The second road type, the undivided highway has two lanes in each driving direction. In the latter, the vehicle having an accident can affect both driving directions. Hence, all vehicles approaching the position of the accident are part of the zone-of-relevance. Refer to figure 1 that sketches the scenarios described above.

Each vehicle on the road moves at a constant, randomly chosen velocity. For the sake of simplicity, we do not model complex maneuvers like lane changes or overtaking. Furthermore, we assume relatively dense traffic while still having free flow. We then determine the distribution of velocity from a traffic model by Heidemann [6]. Two parameters define this model: the average velocity and the traffic density. For the divided highway scenario, the velocity varies around the value of 130 km/h and the traffic density is approximately 5 veh/km per lane. The undivided highway is characterized by an average velocity of 70 km/h and an average density of 25 veh/km per lane. Table 2 summarizes the parameters of these scenarios.

6 Simulation Runs and Results

We observe the number of informed vehicles during a message dissemination. Thus, we measure the effect of the protocol as a combination of the multihopping and the medium access strategy. We define the function $I(t)$ in equation 2 for one message dissemination process. The value of $I(t)$ denotes the rate of informed equipped vehicles inside the zone-of-relevance over time.

$$I(t) = \begin{cases} 0 & \text{if } E(t) = \emptyset \\ \frac{|iE(t)|}{|E(t)|} & \text{otherwise} \end{cases} \tag{2}$$

$$\text{where} \quad E(t) = \{e \text{ equipped vehicle} \mid e \text{ in zone-of-relevance}\}$$
$$iE(t) = \{e \in E(t) \mid e \text{ informed}\}$$

For simplicity, the time $t = 0$ represents the beginning of the message dissemination. In order to compare different simulation runs, we characterize the message dissemination process by the maximum $maxI$ of $I(t)$ for all $t > 0$. This metric is similar to the "Accuracy of Multicast Delivery" in [12] if the set of nodes inside the zone-of-relevance remains constant during the multihopping process. We also define $firstI$ as the minimum t such that $I(t) = maxI$.

The process of message dissemination depends heavily on the number of equipped vehicles on the road. In the beginning of market penetration, only a small number of vehicles will be equipped. Nevertheless, a robust system should also work when the success on the market place leads to broad deployment. Thus, we varied the percentage of equipped vehicles from 5 % up to 100 % to cover extreme values as well as to study the transition period. For the divided highway scenario, we executed 50 simulation runs for each set of parameters. Due to the high vehicle density in the undivided highway scenario, we were only able to run the simulator 20 times for each set of parameters.

We computed the values of $maxI$ and $firstI$ for every message dissemination process. The mean values over the per-

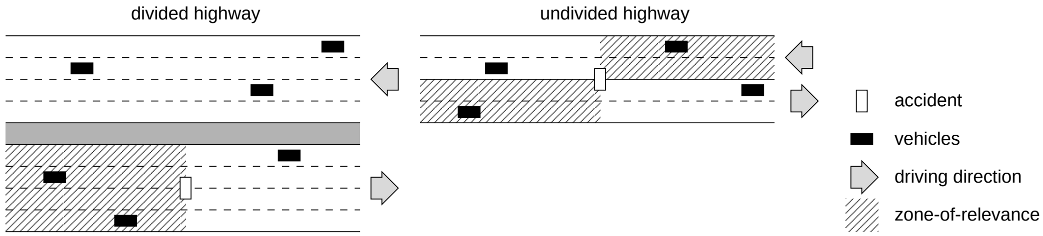

Figure 1: Sample scenarios for different road types

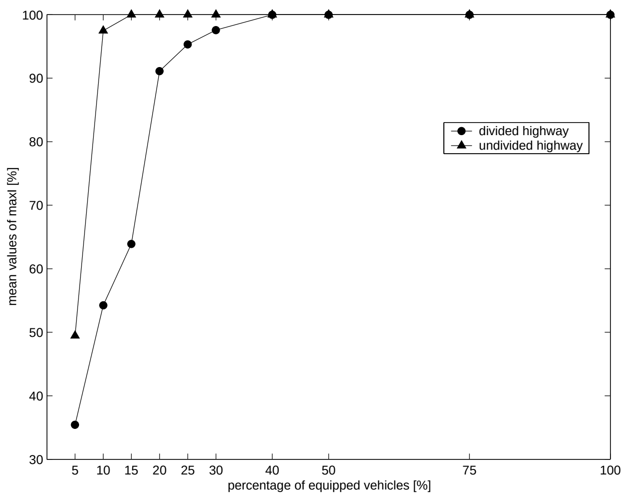

Figure 2: Results of *maxI* for both road types

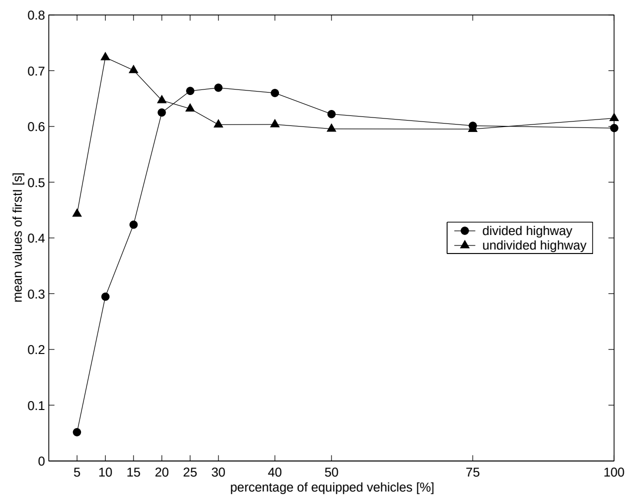

Figure 3: Results of $firstI$ for both road types

centage of equipped vehicles for both metrics and road types are printed in figures 2 and 3.

The results of *maxI* for the divided highway show when 15 % or less vehicles on the road are equipped, not more than 65 % of the vehicles in the zone-of-relevance are reached. This poor performance is due to the average number of equipped vehicles in communication range (5 %: 1.2 veh, 10 %: 2.4 veh, 15 %: 3.6 veh). Thus, the network is likely to be disconnected for small deployment rates of the system. When the percentage of equipped vehicles increases beyond 20 %, the proposed algorithm quickly reaches a sufficient number of 90 % and more of the intended recipients. The message dissemination process shows better results for the undivided highway. Here, we assumed denser traffic because of lower average velocity. Plus, the zone-of-relevance stretches into both directions leading to more relevant receivers within the circular transmission area. For only 5 % equipped vehicles, we have an average of three receivers in vicinity of a sender leading to a mean value of 49 % informed vehicles. Nevertheless, the network can still be partitioned for specific simulation runs in this scenario. Again, the more vehicles on the road are equipped, the closer the results are to the maximum of 100 % informed vehicles.

The resulting curves of $firstI$ denote the duration of reaching *maxI* for a dissemination process. For small numbers of equipped vehicles, the packets that inform a vehicle perform less hops as a consequence of network partition. Once *maxI* saturates at 100 %, the time $firstI$ decreases and then stabilizes around 600 ms for both road types. This duration can be decomposed into a sum of three values. The first value accumulates the transmission time and equals 180 ms: A minimum of 9 hops ($\lceil 5 \text{ km}/600 \text{ m} \rceil$) is needed to cover the zone-of-relevance and each time the transmission lasts 20 ms. The second value is the total of static computation time that a receiver needs to perform the multihopping algorithm. Therefore, the total computation time is the sum of at least 8 forwarding procedures of 50 ms each and calculates to 400 ms. The remaining value of 20 ms denotes the sum of waiting times for the outmost sender in each hop. According to equation 1, an average waiting time of 2 ms corresponds to an average distance of 570 m from the sender – thus, the outermost equipped vehicle is approximately 30 m away from the border of the transmission area.

7 Conclusion and Outlook

We presented an approach to disseminate a message among highly mobile hosts like vehicles in road traffic. As an example, vehicles equipped with inter-vehicle radio communication propagate a warning message about an accident. The proposed and implemented protocol combines a medium access scheme derived from IEEE 802.11 with a multihopping algorithm. Also, we modeled two different road types: a divided and an undivided highway.

Simulation results are generated for different rates of equipped vehicles on the road. The dissemination of the message reaches on average 35 % (divided highway) and 49 % (undivided highway) of the destination group when only 5 % of the vehicles on the road are equipped. Over 90 % of the equipped vehicles inside the zone-of-relevance are informed for deployment rates of 20 % and more.

All simulation runs proved that reaching the maximum of equipped vehicles lasts no longer than 1 s covering a stretch up to 5 km. Thus, this approach could indeed inform drivers of potentially dangerous traffic situations while there is still time to avoid them.

Further research will be necessary to overcome the problem of lacking communication partners for small numbers of equipped vehicles on the road. We currently investigate approaches to let the oncoming traffic wait longer with forwarding the packet until new receivers move into their transmission area.

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