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A Reliable Robust Fully Ad Hoc Data Dissemination Mechanism for Vehicular Networks

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Abstract

Many applications in vehicular networks need the data to be disseminated from a source vehicle to a large number of vehicles in the network. Although many solutions to this problem have been previously proposed by the research community, some challenges and failure scenarios still remain unsolved particularly when the forwarding vehicle is located at an intersection and it wants to disseminate the data to all the intersecting road segments. In this paper, we first evaluate some of the previously proposed directional *mode (along the straight roads) data dissemination mechanisms and then integrate the one with the best performance with our novel reliable robust* intersection *mode data dissemination mechanism in order to come up with a united mechanism for disseminating data both along the straight roads and at intersections. The effectiveness of our proposed mechanism is verified by performance evaluations.*

1. Introduction

Inter-vehicle communications (IVC) have gained a great momentum recently and a variety of applications are anticipated to be developed over vehicular networks. In classical vehicular systems, traffic and emergency information is detected by sensors mounted along the roadside, collected and interpreted in computing centers, and distributed to the vehicles by means of radio broadcast stations or cellular networks. In addition to their high costs, these centralized infrastructure-based systems cannot provide detailed local information for vehicles, because of their limited data rate. Moreover, since the vehicles are not communicating directly, the communication delays can be intolerably high for some applications. Consequently, infrastructure-less distributed ad hoc vehicular networking solutions, called vehicular ad hoc networks (VANETs), have gained popularity among researchers recently.

An extensive number of applications in VANETs need a robust, reliable, and bandwidth-efficient mechanism for data dissemination between vehicles. However, data dissemination is a challenging task in VANETs, due to a highly variable network topology [1][2], frequent network fragmentation when vehicle density is low, and the fact that movement of vehicles are constrained to pre-defined roads with specific speed limits [3]. Some of the applications that use data dissemination include safety applications such as car accident or slippery road notification, traffic and road information sharing in intelligent transport systems (ITS), and also non-safety-oriented applications such as sale advertisements or announcements for marketing purposes. Throughout the paper, we refer to the area in which the data is required to be disseminated as the *zone-of-relevance*.

While most of the previously proposed data dissemination mechanisms operate successfully along straight roads, they encounter some challenges for disseminating data around intersections. In this respect, some recent work has differentiated data dissemination along straight roads (*directional* mode) and data dissemination around intersections (*intersection* mode) [4]-[6]. In this paper, we firstly review a number of existing fully ad hoc *directional* mode data dissemination mechanisms and after evaluating them by means of simulation, we select one with the best performance in terms of delay, efficiency and reliability as the *directional* mode mechanism in our integrated data dissemination mechanism (Section 2). Some failure scenarios of current *intersection* mode data dissemination mechanisms are summarized in Section 3 that motivate the proposition of our novel *intersection* mode data dissemination mechanism in Section 4. We integrate this *intersection* mode solution with the *directional* mode mechanism mentioned above to form our united data dissemination mechanism, which is the main contribution of this paper. Section 5 concludes the paper and brings up the direction of our future work.

2. Directional Mode Data Dissemination Mechanisms

Simple flooding and proactive algorithms [7], [8] cause a significant amount of redundancy and collisions in the network. In order to reduce redundancy and collisions, the authors of [9] offer a broadcast algorithm in which the messages are forwarded only if they have arrived from the right direction. However, in the presence of a high node density (we use the terms *node* and *vehicle* interchangeable throughout this paper) and heavy traffic, the network is still prone to the broadcast storm problem [10]. One of the seminal data dissemination mechanisms, which efficiently addresses the broadcast storm problem as well as the hidden node problem, is urban multi-hop broadcast (UMB) [4]. The directional mode data dissemination mechanism used in UMB is as follows.

Unlike flooding-based protocols, in UMB, in order to cope with the broadcast storm problem, each vehicle forwards the packet only to the node in the farthest distance within its radio transmission range and it does so in a beacon-free manner (without exchanging location information among neighbor nodes). To mitigate the hidden node problem, a handshake protocol similar to the Request-to-Send (RTS)/Clear-to-Send (CTS) protocol in IEEE 802.11, called Request-to-Broadcast (RTB)/Clear-to-Broadcast (CTB) is used. The RTB packet contains the position of the source node as well as the intended broadcast direction. When a node in the direction of the dissemination receives the RTB, it transmits a jamming signal called a *black-burst* with the length proportional to the distance between the node and the source (the farthest node sends the longest black-burst). At the end of its black-burst, every node listens to the channel. If it finds the channel idle, it infers that it is the farthest node to the source. So, it replies to the RTB by sending back a CTB packet to the source. The actual message and an Acknowledgment (ACK) are sent afterwards.

Another promising data dissemination mechanism is data pouring with intersection buffering (DP-IB) [6]. In the directional mode data dissemination mechanism of this scheme, vehicles use periodic beacon messages to report their locations, directions and velocities to each other. To mitigate the broadcast storm problem [10], each message forwarding vehicle selects the farthest vehicle in its neighbor list (obtained through beaconing), which is in the data dissemination direction, as the next forwarder.

Table 1. Mobility-related and wireless communication-related parameters used in the simulation

Highway length	4 kilometer
Vehicle density	5 ~ 40 vehs/km per lane
Average speed	15 ~ 35 m/sec
Simulation time (used for computing delivery ratio)	2000 sec
Emergency message size	2500 bit
Transmission range	100 m
MAC Layer	IEEE 802.11
Max. Contention Window	32
Background safety traffic	10 kbps
Data rate	1 Mbps
Beacon interval	2 ~ 5 beacons/sec
Beacon size	512 bit
Radio Model	Two Ray Ground

Since both UMB and DP-IB have efficient, reliable and robust directional data dissemination mechanisms, we formed a simulation system to compare their performance in order to select one of them as the directional mode solution in our integrated data dissemination mechanism. The simulation is based on a 4 kilometer two-lane road. Since in most data dissemination applications the concern is delivering the messages in a low-latency reliable manner and since both UMB and DP-IB are 100% reliable, we compare them in terms of latency and define it as the total time needed for delivering the emergency packet to all of the vehicles in the 4 kilometer zone-of-relevance. In our simulation scenario, we assume that the vehicle closest to the left hand side edge of the zone-of-relevance has detected an emergency event and is therefore responsible for forwarding the message throughout the zone-of-relevance. The parameters used in the simulation system including those related to the mobility model and the wireless communications system are listed in TABLE 1.

For the case in which the node density is 20 vehicles per kilometer per lane, and the vehicles are sending two beacons per second, the latency of the two schemes versus the average speed is depicted in Figure 1. Each result was obtained by taking the average value from 30 simulation runs. The reason that the latency decreases when speed increases is that at some points in time, due to fragmentation the vehicles should carry the messages until they find the next node to forward the message to. As observed in Figure 1, UMB has lower delays than DP-IB. One reason is that in DP-IB, the next forwarder that a vehicle chooses from its neighboring list might have already left the area within the transmission range of the vehicle. In order to cope with this problem, we increased the beaconing frequency. A higher beaconing frequency corresponds to more frequent updates of the neighbor list. As this problem becomes more critical when the average speed of the vehicles increases, we simulated our system for the average vehicle speed of 35 m/s (Figure 2). Although the latency decreases as the beaconing frequency is increased, it is still greater than that of UMB. This is due to the fact that contrary to UMB, DP-IB is prone to the hidden terminal problem since it uses the two-way hand-shake mode of the IEEE 802.11 MAC standard, and also the fact that the beaconing itself

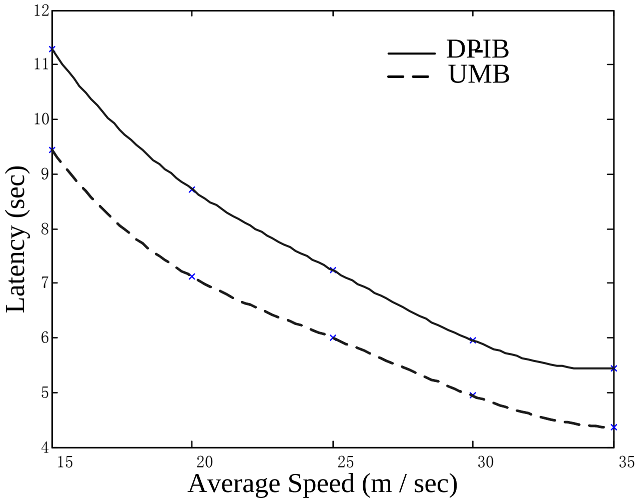

Figure 1. The comparison between UMB and DP-IB when employed on a straight highway (for 20 vehs/km per lane and 2 beacons per second in DP-IB)

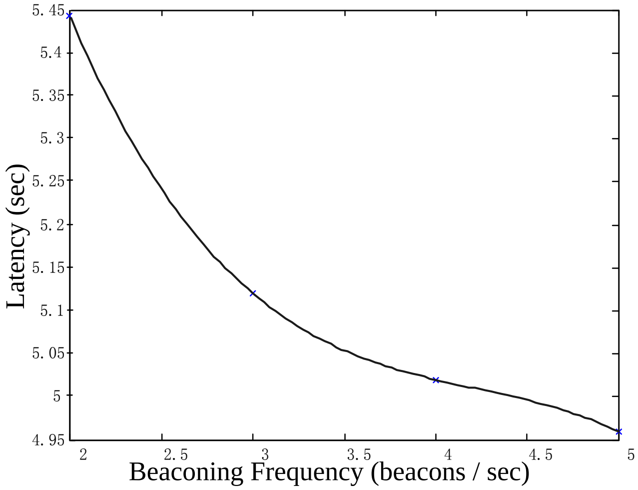

Figure 2. The latency decreases when the beacon interval in DP-IB increases, but still remains greater than UMB (for avg. speed of 35 m/sec)

imposes some extra traffic and causes more delays in the network. On the basis of the results demonstrated in this section, we select UMB as the directional mode solution of our integrated data dissemination mechanism. Next, we develop a suitable mechanism for data dissemination around intersections.

3. Intersection Mode Data Dissemination Mechanisms

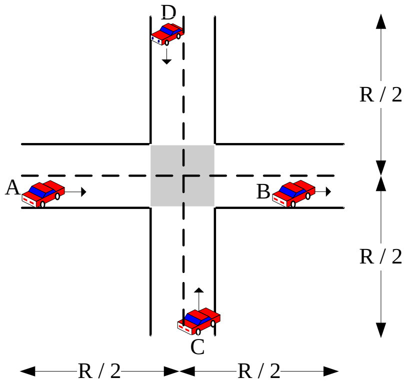

Figure 3.a. *A* forwards the message to *B* which is out of the intersection

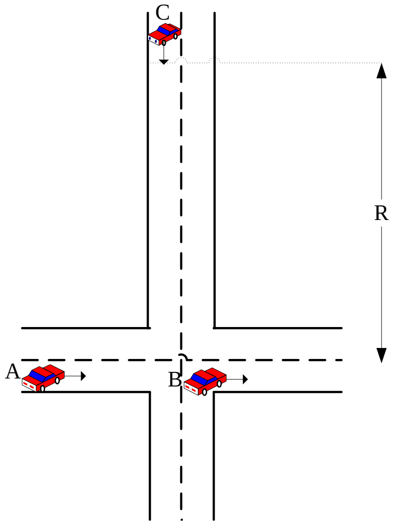

Figure 3.b. *A* forwards the message to *B* which is inside the intersection, but leaves the intersection before *C* arrives at its transmission range

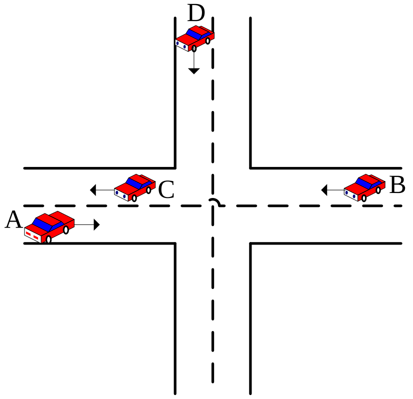

Figure 3.c. *A* had better forward the packet to entering node *B* rather than leaving node *C*

DP-IB and UMB rely on repeaters installed at the intersections to forward the messages along the intersecting roads. However, we are looking for an infrastructure-independent fully ad hoc solution. To the best of our knowledge, the only fully ad hoc data dissemination mechanism that explicitly addresses data dissemination at intersections is ad hoc multi-hop broadcast (AMB) which is proposed by the authors of UMB in their other works [5]. This is why we consider the intersection mode mechanism in AMB as a baseline mechanism to compare our proposed intersection mode mechanism with. AMB has the same directional mode data dissemination as UMB; however, it is an extension of UMB in the sense that instead of repeaters, an ad hoc solution is used at the intersections. In AMB an *intersection region* is defined starting from R/2 m before and extending to R/2 m beyond the intersection, where R is the radio transmission range. The first vehicle chosen in the intersection region (referred as the HUNTER vehicle) is responsible for finding the vehicle closest to the intersection (with reference to the centre of the intersection). The radius of the intersection region is defined as R/2 m, because the HUNTER tries to select a closer vehicle to the intersection and its transmission range should cover the points closer to the intersection than itself. To select the closest vehicle to an intersection, the vehicles set the lengths of their black-bursts proportional to reverse of their distance to the intersection. The vehicle closest to the intersection is responsible for forwarding the message along the intersecting roads. Since RTB packets contain the intended broadcast direction, a new RTB packet should be sent for each direction.

Now, we elaborate on some scenarios in which the AMB mechanism fails. The first scenario is depicted in Figure 3.a. Let node *A* be the HUNTER. The moving directions of the vehicles are also specified in the figures. Node *A* forwards the message to node *B* (the closest vehicle in its line-of-sight to the intersection). However, node *B* is already out of the intersection (the area in gray in Figure 3.a), and when node *C* or *D* arrives at the intersection, node *B* has already left the intersection region and neither of them will be notified.

Another failure scenario is shown in Figure 3.b. In this scenario, node *A* forwards the message to node B, which is inside the intersection this time. However, node *B* will leave the intersection before node *C* comes inside its transmission range and gets notified. Another scenario is shown in Figure 3.c. In this scenario node *A* delegates the message forwarding responsibility to node *C* (the closest node to the intersection). However, node *C* is leaving the intersection and therefore there will be no way to notify node *D*. If node *A* had instead delegated the message forwarding responsibility to node *B*, since node *B* is entering the intersection, node *D* would have got notified. In all of these failure scenarios, the message leaves the intersection region without making sure that it has been disseminated along all the intersecting road segments. In the next section, we propose an effective solution to this issue.

4. Proposed Enhanced Intersection Mode Data Dissemination Mechanism

In this section, we present our proposed enhanced intersection mode data dissemination (EIDD) mechanism, which is fully ad hoc in its operations and highly robust. The idea is to keep the emergency message in the intersection long enough to ensure that the message is forwarded to all the intersecting road segments. The procedure is that when a vehicle in the intersection region receives the message, it attaches three bits to the header of the message, provided that the crossroad is composed of two perpendicular roads (considering that vehicles are all equipped with

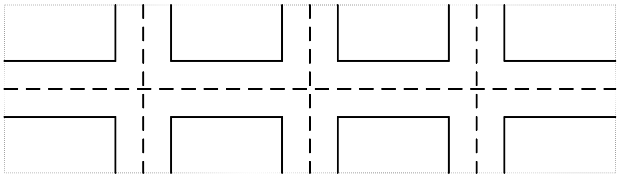

Figure 4. The primary road intersected by three secondary roads

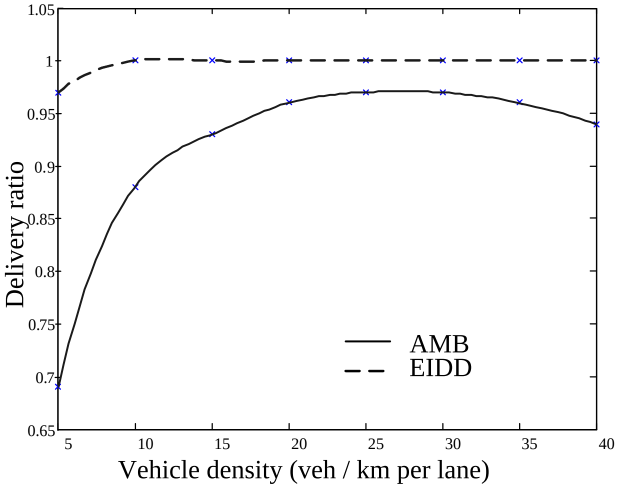

Figure 5. The delivery ratio of EIDD is considerably higher than AMB and approximately 100%

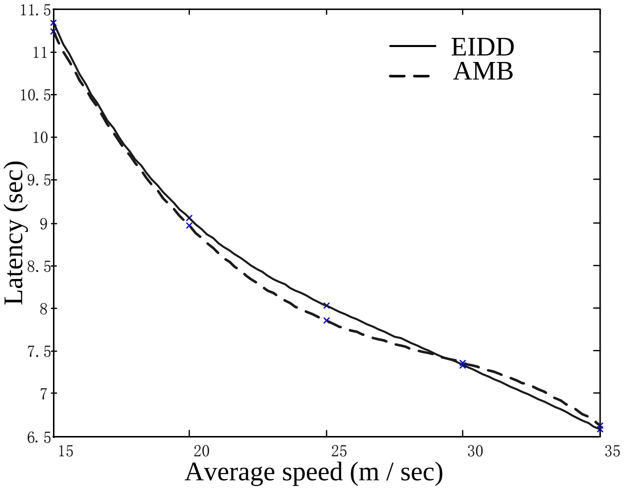

Figure 6. EIDD and AMB have approximately similar delays

digital maps, they use more number of bits if the intersection is more complex). Each of the three bits corresponds to the dissemination of the message to one of the intersecting road segments. The bits are initially set to zero and their order is determined according to the direction the message enters the intersection. Since every vehicle is assumed to be equipped with a GPS, it can simply identify the direction from which it has received the message. For instance, if the message is coming to the intersection from the west, the three bits will correspond to road segments on the north, east, and south respectively. The vehicle is then responsible for forwarding the message to all the intersecting road segments, and at the same time if it finds a vehicle closer than itself to the intersection, it delegates the forwarding responsibility to that vehicle. Whenever the vehicle responsible for forwarding the message receives an acknowledgement from any of the required road segments, it sets the corresponding bit to one. Delegating the forwarding responsibility to the node closest to the intersection continues until all the three bits are set to one or the message expires. In order to increase the chance of delivering the packet to all the directions and minimize the delay, we define the intersection region starting from R m before and extending R m beyond the intersection.

To compare the performance of our proposed EIDD mechanism with the intersection mode data dissemination mechanism used in AMB, we formed another simulation system. The zone-of-relevance is shown in Figure 4, with three secondary roads running vertically intersecting with one primary road running horizontally. The length of the primary road is again 4 kilometers and we assume that the vehicle closest to the left hand-side edge of the zone-of-relevance has detected the emergency event. Also the directional mode data dissemination mechanism employed along the straight roads is that of UMB and the vehicle density in the primary road is set twice that of the secondary roads. Other parameters are the same as before (TABLE 1).

We expect that EIDD performs better than AMB in terms of reliability and robustness as the vehicle density decreases. To study this issue, we obtained the delivery ratio (the percentage of the vehicles that finally gets notified in the simulation time) in terms of vehicle density. As it is observed in Figure 5, the delivery ratio of EIDD is much higher than AMB, and 100% for approximately all the vehicle densities (except when the average distance of the vehicles becomes lower than the transmission range). As the vehicle density increases, the delivery ratio of AMB reaches to a maximum and decreases afterwards due to larger number of collisions. However, the delivery ratio of EIDD appears to remain 100% which corresponds for its scalability as the vehicle density increases.

For the case where vehicle density is 20 vehicles per kilometer per lane, we obtained the average latency of AMB (in the simulation runs in which the message is delivered to all the vehicles) and EIDD for different average speeds. The two schemes have approximately similar latencies (Figure 6).

5. Conclusion and future work

In this paper, we have studied the data dissemination issue in vehicular ad hoc networks. First, we have introduced a number of directional mode data dissemination mechanisms and shown by means of simulation that the directional mode data dissemination mechanism used in UMB outperforms its peers. We have brought up a number of challenges and failure scenarios that call for our novel fully ad hoc enhanced intersection mode data dissemination mechanism. We have evaluated our united solution in terms of robustness, reliability and scalability, and its effectiveness is confirmed. We believe that our proposed solution could be a good candidate for practical vehicular networks.

Currently we are studying the use of infrastructure on the performance of the data dissemination mechanisms in vehicular networks to see if it makes a considerable improvement over fully ad hoc solutions. Furthermore, considering other more complicated applications that call for the use of routing protocols and might impose the co-existence of various access technologies (in the form of a heterogeneous network) is also the subject of our future research.

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