QoS support for traffic safety applications in VANET communication infrastructures

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ABSTRACT
Vehicular traffic safety applications are used to increase the road safety by decreasing the number of traffic accidents on roads. This type of vehicular applications uses a VANET (Vehicle Ad-hoc Network) for communication. An important issue associated with V2V communications used for traffic safety applications (TSAs) is the Quality of Service (QoS) support. This paper studies and qualitatively compares several solutions used in V2V communications for the support of QoS. In order to perform this comparison several comparison criteria are derived. Each QoS solution can satisfy a subset of the derived criteria. However, none of the proposed QoS solutions can satisfy all the derived criteria.

Keywords
QoS, traffic safety applications, V2V, IEEE 802.11e, wireless, VANET.

1. INTRODUCTION
More and more cars, trucks motorcycles and other means of transportation can be found on the road today. With the increase of the road vehicle traffic, the problems and accidents occurring on the road are also increasing. Vehicle traffic safety applications (TSAs) can be used to increase the road safety by preventing and decreasing the number of road accidents. Such vehicular applications can be provided by using VANET (Vehicle Ad-hoc Networks) communication. In a VANET (1) vehicles are communicating with each other and (2) vehicles are communicating with fixed network entities located at the side of road highways (RSUs – Road Side Units), using the same ad-hoc wireless technology, such as IEEE 802.11p [1]. In case of a dangerous situation on the road, a collision for example, the vehicles involved or endangered by this situation can be warned in time so action can be taken by drivers before they notice the situation themselves. In this way more damage or accidents, even a chain collision, can be prevented (see Figure 1) In Figure 1, vehicles A and B cause a collision. Immediately after this collision both vehicles send emergency messages to the vehicles behind them on the same road. Those vehicles send the message further along the road to warn more vehicles. After receiving the emergency messages, the driver can take action suited for the situation at hand.

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Figure 1: A collision between vehicle A and B, followed by a transmission of emergency message

It should be clear that the data messages used by such TSAs should have a high communication and processing priority compared to other types of vehicular applications, such as entertainment based vehicular applications. This means that the data messages used by TSAs should be disseminated through other vehicles on the road, quickly, with a very low communication delay and data packet loss. So these warning data messages should be delivered in a very short time period, to all the vehicles on the same road that can encounter the collision. To guarantee this type of delivery, TSA’s impose several Quality of Service (QoS) demands on VANET communication channels. Currently there are several solutions proposed which can solve or help meeting these QoS demands. This paper answers the following main research question:

“Which QoS solutions can be applied in VANET communication infrastructures for the support of traffic safety applications?”

This main research question is divided in three research sub-questions in order to answer this main question correctly and in a structured way:

1. Which QoS requirements/criteria are traffic safety applications imposing on VANET communication infrastructures?
2. Which VANET algorithms, proposals, architecture solutions can be used to satisfy the QoS requirements/criteria?
3. How do these solutions satisfy the QoS requirements/criteria?

The research approach followed in this paper is a combination of a literature study and qualitative comparison. During the literature study, the Google Scholar and the IEEE searching engines were used. This paper is organized as follows. Section 2 describes the QoS comparison criteria and answers the first research question. Section 3 describes several QoS solutions and answers the second research question. Section 4 describes a comparison between the different QoS solutions and answers
the third research question. Section 5 concludes and recommends future activities.

2. QOS COMPARISON CRITERIA

Pfart et al define QoS as “the collective effect of service performances which determine the degree of satisfaction of a user of the service.”, from [6]. There are essentially two ways to provide QoS for network applications: by resource reservation, from the network’s viewpoint, and by behavior adaptation, from the application’s viewpoint, see [6]. When QoS is supported then the system behavior can be controlled such that requirements on several performance parameters such as delay, jitter and packet loss can be satisfied.

A number of requirements/criteria that can be used to compare several QoS solutions are listed below.

Criterion 1: Usage of different radio channels for different types of applications/messages.

The physical layer of the wireless technologies used by VANET communications should be able to use different radio channels for the various types of vehicular applications. In this way, specific radio channels can be allocated for the traffic generated by TSAs.

Criterion 2: Media Access Controller (MAC) layer can support QoS differentiation.

The MAC layer of the wireless technology should be designed in such a way that QoS differentiation is supported. In this way data messages associated with TSA will be able to be handled by the MAC in a different way than data messages associated with other types of applications.

Criterion 3: Support of an increased end-to-end throughput while achieving fairness in bandwidth usage between users.

The QoS solutions should be designed in such a way that the end-to-end throughput associated with the TSAs is increased while achieving a fair bandwidth usage between TSA users. This criterion can be satisfied by functionalities that could be provided by the network, transport or application layers supporting the VANET communication.

Criterion 4: Achieving low latency in delivering emergency warnings

QoS solutions should be designed in such a way that the latency of emergency warning messages is decreased. This can be accomplished by differentiating between different types of TSA messages. TSA messages used for emergency warnings should get a higher communication and processing priority than other types of TSA messages.

3. QOS SOLUTIONS

Several algorithms, protocols and architecture solutions that can be used to support QoS in VANET communications have been proposed. This section will give an overview of several research papers that are proposing possible solutions for various QoS problems regarding wireless communication in VANET. After a general description of the goals and achievements of those papers, possible QoS solutions are highlighted.

3.1 Quality of Service Provisioning in 802.11e Networks

One important solution is the 802.11e MAC standard amendment [6] used to support QoS differentiation at the MAC layer of IEEE 802.11. It is important to note that the IEEE 802.11p wireless technology [1] used by TSAs is applying the MAC QoS differentiation provided by IEEE 802.11e. The 802.11e is a new MAC QoS differentiation enhancement developed by the IEEE 802.11 working group, “to provide differentiation mechanisms at the Medium Access Control MAC layer” [7]. The IEEE 802.11e solution can be used to solve three main challenges for QoS support, (1) the handling time-varying network conditions, (2) adapting to varying application profiles and (3) managing link layer resources.

The 802.11e QoS framework defines two modes of operation, (1) the HCCA (Hybrid Coordination Control Access) and (2) the Enhanced Distributed Channel Access (EDCA). These methods enhance the MAC functionalities specified in IEEE 802.11a/b/g.

The Enhanced Distributed Channel Access (EDCA) classifies traffic through introduction of access categories (AC’s). The differentiation in access priority between each AC is done by setting different values for the channel access parameters, see Figure 2. The most important additions in these parameters are the arbitrary interface space number (AIFSN), Contention Window (CWmin and CWmax) and the transmission opportunity (TXOP) limit. A description of how this is accomplished is given in [2, 7]. This technique is similar to the functionality of the distributed coordination function (DCF), used in IEEE 802.11a/b/g. The access prioritization of the ACs is achieved by giving different values for the channel access parameters (AIFSN, TXOP, CW).

The HCCA uses a new defined coordinating function called the hybrid coordination function (HCF). This mode of operation uses polling, where the HCF can be seen as a centralized controlling entity that via polling controls the access of the entities that are using this mode of operation. The HCCA channel access prioritization is shown in Figure 3.

The main idea is that flows with strict QoS requirements send reservation request to the AP containing flow information. Thereafter the AP decides the minimum service interval (SI) for all nodes, time duration between successive polls for the node, and the TXOP for each node.
3.2 A Distributed MAC scheme for Emergency Message Dissemination in Vehicular Ad Hoc Networks (DMEMD)

In [5] a solution is proposed on a new medium access control (MAC) scheme to provide strict priority for individual packets. In particular, [5] focuses on dissemination of emergency messages in VANETs, which need a timely and lossless medium access. According to [5] the proposed MAC scheme does mainly two things namely, it realizes strict packet-level priority scheduling for emergency packets in a fully distributed way and it supports multiple levels of strict priority for emergency packets. This solution is denoted in this paper as Distributed MAC scheme for Emergency Dissemination (DMEMD).

The proposed MAC scheme basically operates with three radio channels; one channel for nonemergency messages (regulated by a MAC protocol such as IEEE802.11), one channel for emergency messages and one control channel for pulses, called priopulses. While sending an emergency message, the sending node also sends priopulses in the control channel (see Figure 4). In Figure 4, Node A is the emergency message source, node B is a neighbor of node A, and node C is a hidden terminal to node A. Hidden nodes, represent a situation where a node, say node A, which has radio coverage with another node, say node B, it cannot receive messages sent by node B due to a hidden node, node C. Node C is located between the two other terminals and blocks the communication between them. Because of this hidden node situation, a listening node, not being able to sense a sending node it can deduce that a channel is clear when it actually is not. The priopulses ensure that an emergency packet receives the actual priority that it deserves for its level of emergency, which is decided and added in the packet header by the application layer. In this way, the hidden nodes are suppressed when the emergency message is in transmission. Figure 5 shows the structure of the priopulse. A priopulse consists of an active part of fixed length and a pause part of random length. The random pause part is composed of a contention window and a residual random pause. Furthermore, the fixed size contention window is cut into sub windows.

When an emergency message arrives at a node, the node starts a backoff timer, at the moment that the control channel has been sensed idle. Otherwise it keeps monitoring the control channel. For a full description of this proposed MAC scheme see [5].

In [5] the results of several simulation experiments are discussed. From these experiments it can be derived that when typical traffic load is applied then no packet loss on emergency packets is observed. Furthermore, the proposed scheme achieves timely and lossless medium access for emergency packets in VANETs. Also the strict priority for emergency packets is quite well supported by the proposed scheme.

3.3 A cross layer multihop delivery protocol with fairness guarantees for vehicular networks (CVIA)

In [4] a new communication protocol is introduced, i.e., the controlled vehicular internet access (CVIA) protocol, which is a protocol for vehicular internet access along highways. The goal of the solution is to increase the end-to-end throughput while achieving fairness in bandwidth usage between road segments. To do this, [4] proposes a way to divide the road into segments and controlling the active time of each of those segments, see Figure 6. By using fine-tuned protocol parameters, this solution provides fairness among the roads segments. Note that the proposed protocol uses fixed RSUs along the road and that their range can be increased with multi-hop communication. The coverage range of a RSU is called virtual transmission radius (VTR). This solution assumes that the involved vehicles are able to support GPS (Global Positioning System).
The goal of the CVIA is stated as mitigating the hidden node problem while gathering local packets, avoiding contention and providing fairness among segments by controlling the contents of packet trains. For an explanation of the hidden node problem see section 3.2.

From the discussed performance evaluation experiments it can be deduced that in comparison with the IEEE 802.11 protocol, the CVIA protocol distributes the throughput fairly to all segments even if the offered load is increased, where in the IEEE 802.11 protocol the outer segments experience starvation. This greatly affects fairness, stated in this paper as: “providing equal throughput to all segments”.

Regarding delay, which is defined as the time elapsed between the instant the packet enters the transmission queue of the source and the reception time of the packet by the final destination the following conclusions are derived. Again in this case the IEEE802.11 protocol has a large average delay of packets coming from the outer segments, compared to CVIA. Another positive result, compared to IEEE 802.11, is the packet failure rate. Since the CVIA protocol avoids hidden nodes, the probability of a packet collision is much lower than in the 802.11 protocol. An overall conclusion on performance evaluation is that the CVIA protocol has a higher end-to-end throughput when compared with the IEEE 802.11 protocol.


An extension to the previous described CVIA protocol is the Controlled Vehicular Internet Access protocol with QoS (CVIA-QoS) described in [3]. The CVIA-QoS is defined as: “A cross-layer solution for vehicular multihop networks spanning MAC and routing functions with infrastructure support”, from [3]. The CVIA protocol is designed only for best-effort traffic, while the most important contribution of the CVIA-QoS is the provision delay bounded throughput guarantees for soft real-time traffic. After satisfying the QoS demands of the soft real-time traffic, the CVIA-QoS solution allocates the remaining bandwidth to the best-effort traffic. In this QoS solution, each time slot is divided in two periods, a high priority period (HPP) and a low priority period (LPP). At the beginning of the HPP, each session that requests service, sends registration packets. Via different phases the collected packets are eventually propagated to the gateway (RSU) in packet trains in one time slot [3], see Figure 7. The different phases used in the CVIA-QoS protocol are shown in Figure 7. The HPP is a new phase that is defined in [3], while the LPP is defined in CVIA, see [4].

![Figure 7: Phases in the CVIA-QoS protocol, copied from [3]](image)

Several performance evaluation experiments have been described in [3]. The main conclusions are: first the best effort traffic throughput capacity of the CVIA-QoS is smaller than the one supported by CVIA. This is because the CVIA-QoS protocol is able to allocate some portion of its throughput to provide delay bounded throughput guarantees to real-time traffic. Second the throughput of real-time traffic is not affected by the best-effort load in the channel, because of the admission control and polling of the real-time packets without contention.

3.5 A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning (VCWC)

A communication protocol described in [8] is able to help solve several challenges in Vehicle to Vehicle communication and VANETs. The main challenge addressed in [8] is achieving low latency in delivering emergency warnings. The authors of [8] try to “design an effective protocol, comprising congestion control policies, service differentiation mechanisms and methods for emergency warning dissemination.”, from [8]. The proposed protocol is called Vehicular Collision Warning Communication (VCWC). This protocol mainly tries to achieve the situation that in case of a collision all the cars behind the collision, and moving on the same road, are warned in time by the VCWC, while achieving a low emergency warning message (EWM) delivery delay. A couple of assumptions are made by in VCWC: (1) a vehicle is able to obtain its own geographical location, (2) it is equipped with a wireless transceiver and (3) it has a transmission range of 300 meters. Two important challenges in regard to emergency messages during a collision are addressed:

- Stringent delay requirements immediately after the emergency.
- Differentiation of emergency events and elimination of redundant emergency warning messages (EWM’s)

The elimination of redundant EWM’s is done by a proposed mechanism namely, the state transmission mechanism. By doing this multiple AV’s could coexist at low cost of channel bandwidth.

Using simulation experiments, [8] concludes that the proposed VCWC protocol can satisfy the emergency warning delivery requirements.

4. COMPARISON OF QOS SOLUTIONS

This section will compare the criteria from section 2 with the solutions given in section 3. To compare this in a structured way for each criterion a subsection is made. Under each criteria every solution from section 3 is compared with this criterion and verified whether the solution satisfies the criterion.
4.1 Usage of different radio channels for different type of applications/messages

The first solution which is described in section 3.1 is the 802.11e MAC standard amendment. This solution focuses on providing differentiation mechanisms at the MAC layer. These features are applied at the MAC layer and not at the physical layer. However, the physical layer used by IEEE 802.11p, which uses IEEE 802.11e provides different radio channels for the different types of applications/messages. Therefore, it can be concluded that this solution in combination with IEEE 802.11p meets this requirement/criterion.

The solution described in section 3.2 (DMEMD), does meet the criteria. The protocol makes a distinction between nonemergency messages and emergency messages and uses a different radio channel for each type. So every emergency message sent by a TSA is sent through the radio channel which is reserved for emergency messages.

The CVIA and the CVIA-QoS which are described in section 3.3 and 3.4, respectively, do not use a different radio channel for different types of messages. The VCWC described in chapter 3.5 also does not meet this criterion. The VCWC does not use a different radio channel for different kind of messages.

4.2 Media Access Controller (MAC) layer can support QoS differentiation

This criterion is met by the 802.11e MAC standard amendment. The two modes of operation defined in the IEEE 802.11e are the HCCA and the ECCA. Together they enhance the current MAC functionalities in such a way that QoS differentiation is supported.

DMEMD and VCWC support differentiation, by providing solutions to enhance the dissemination of emergency messages. However, DMEMD and VCWC do not focus on how the MAC layer should provide differentiation to different types of traffic applications. Therefore, it can be concluded that these solutions satisfy this criterion partially.

The CVIA-QoS protocol is a MAC solution that is able to provide QoS differentiation between soft real time traffic and best effort traffic. This solution satisfies this criterion.

CVIA does not satisfy this criterion.

4.3 Support of an increased end-to-end throughput while achieving fairness in bandwidth usage between users

The 802.11e MAC standard amendment tries to improve the MAC layer and provide them with differentiation mechanisms. It gives different messages different kinds of access categories, by doing this the end-to-end throughput of messages sent by TSA’s will probably increase because they can be found more important and get a higher priority level. Fairness in bandwidth is achieved by collecting different reservation requests and decide on the service interval for all nodes. However, it is not clear whether this criterion can be completely satisfied, since the support of end-to-end throughput while achieving fairness in bandwidth between users is not discussed in IEEE 802.11e.

Fairness guarantees are given in the CVIA and the CVIA-QoS protocols as well as an increased end-to-end throughput. It does so by dividing the road into segments, see section 3.3 and 3.4, respectively. With these segments the bandwidth is fairly divided. A difference in best effort traffic throughput between the CVIA-QoS protocol and the CVIA protocol is that the best effort traffic throughput supported by CVIA-QoS is lower than the one supported by CVIA.

The proposed distributed MAC scheme described in section 3.2, DMEMD realizes a higher end-to-end throughput in a different way. The MAC scheme uses a different channel for emergency messages. This means that messages sent by the TSA have their own channel which will allow those messages to get through without much delay. Fairness in bandwidth is not guaranteed.

The VCWC proposal’s main focus is on achieving low latency in delivering emergency warnings. The VCWC does this with a low cost of bandwidth, but this does not mean that the bandwidth is fairly divided between users.

4.4 Achieving low latency in delivering emergency warnings

The proposed 802.11e scheme achieves a low latency in delivering emergency warnings because of the introduction of different categories for a differentiation in access priority. Because in this case the emergency messages will receive a higher priority they will experience fewer delays.

DMEMD also differentiates between priorities which makes low latency possible. The protocol realizes strict packet-level priority scheduling and it supports multiple levels of strict priority for emergency packets, see section 3.2.

Both CVIA and the CVIA-QoS do not differentiate between priority levels, therefore it is not able to achieve a significant latency reduction in the delivery of data messages. However they do achieve smaller delays for packets coming from the outer segments in comparison with the 802.11 scheme. Moreover, CVIA-QoS differentiate between soft real time traffic and best effort traffic. Therefore, it can be assumed that the data messages associated with CVIA-QoS can experience smaller delays compared to the ones associated with CVIA.

The focus of the VCWC is mainly on supporting this criterion. It achieves low latency in delivering EWMs by being able to change the EWM transmission rate adaptively.

5. CONCLUSIONS AND FUTURE WORK

An important issue associated with VANET communications used for traffic safety applications is the Quality of Service support. In this paper, several solutions used in VANET communications for the support of QoS were briefly described, which were derived using a literature study. These solutions were compared using 4 criteria. The 5 possible solutions that were reviewed were compared using these criteria. The first criterion is met by the IEEE 802.11e (when used within IEEE 802.11p) and the DMEMD solutions. The second criterion is satisfied by the IEEE 802.11e and CVIA-QoS solutions. DMEMD and VCWC satisfy this criterion only partially, while CVIA does not satisfy it. The 802.11 scheme, the DMEMD, CVIA, CVIA-QoS and the VCWC all satisfy the third criterion from the point of view of supporting an increased end-to-end throughput. However from the point of view of fairness, only the CVIA and CVIA-QoS solutions can satisfy this criterion. The fourth criterion is satisfied by all except the CVIA and CVIA-QoS protocols. It becomes clear that none of the proposed QoS solutions can satisfy all the criteria listed in Section 2.

In overall, it can be concluded that none of the QoS solutions presented in Section 3 can satisfy all the QoS criteria listed in Section 2. However, IEEE 802.11e, DMEMD, and VCWC can be considered of being suitable for use in VANET communication for the support of traffic safety applications.

In the future, more research should be done on finding new methods, standards, protocols and architectures which satisfy...
the QoS criteria. Moreover, comparisons using quantitative performance evaluations are needed, in order to quantify the performance differences between the QoS solutions.

6. REFERENCES


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