# Effect of Retransmissions on the Performance of the IEEE 802.11 MAC Protocol for DSRC

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***Abstract*—We propose and evaluate two retransmission-based schemes to improve the reliability of broadcasts in a contention-based MAC, with application to safety messages in dedicated short range communication (DSRC). These improve the reliability of event driven emergency messages without requiring feedback or additional protocol overhead. We also extend the Piggybacked ACK protocol into a feedback-based retransmission scheme. These three schemes can be implemented on top of the 802.11p MAC. We demonstrate by simulation that the packet delivery ratio of event messages is improved in diverse traffic conditions, with a small drop in performance for routine messages. We do not observe a significant improvement from using feedback, compared with the blind retransmission schemes.**

## I. INTRODUCTION

Dedicated Short Range Communication (DSRC) [1] is a protocol which allows vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, which improve road safety and increase transportation efficiency. Among the many candidate applications, cooperative collision avoidance (CCA) [2] has attracted considerable interest in the research community as it can significantly improve road safety. In CCA, moving cars form a network to wirelessly communicate and warn each other and drivers of changing conditions or dangers ahead on the road to avoid accidents. This can be achieved through communication between vehicles of what we call routine and event messages. They are called in [3] routine- and event-safety messages, respectively. The latter are also called event driven emergency messages [4]. The former typically contain information about vehicle state, such as position, direction and speed, and will be broadcast regularly by all vehicles. These messages constitute the majority of traffic load on the DSRC control channel and have a lifetime of a few seconds. The event messages, on the other hand, are triggered by emergency situations such as sudden braking, that break the continuity implied by routine messages. These messages occur only occasionally, but occur in bursts and can contribute significantly to the short-term traffic load on the control channel when they do occur. Clearly the event messages have more stringent requirements for fast and guaranteed delivery, while routine messages may tolerate a higher packet loss rate. To this end, the DSRC medium access control (MAC) protocol has a vital role to play since both the reception and delay of safety messages are heavily affected by the MAC mechanism used for channel access.

Various MAC protocols have been proposed for V2V communications [5]. In this paper we focus on the IEEE 802.11p distributed coordination function (DCF) MAC protocol recently standardized for DSRC applications [6]. DCF is a decentralized MAC protocol based on carrier sense multiple access (CSMA) that can operate with a variety of traffic loads and requires minimal reconfiguration upon a change in topology. Although DCF has both unicast and broadcast operating modes, the latter is more appropriate for CCA application where information is of interest to all nearby vehicles, and association between stations is not required. The broadcast could use multi-hop transmissions to enhance coverage, but recent studies suggest that a single-hop transmission is sufficient in most situations to reach all vehicles in the vicinity of an impending accident [3]. Hence we only consider single-hop broadcast, in contrast to the multi-hop broadcast commonly studied in the literature of wireless ad hoc networks.

Reliable broadcast transmission is challenging because most protocol mechanisms to implement reliability, such as conventional acknowledgements or virtual carrier sensing (Ready-to-send/clear-to-send, RTS/CTS), cause a "storm" of response packets which collide at the original sender. CCA applications typically require a packet delivery ratio (PDR) of at least 90% [1], and it has been suggested [7] that the conventional DCF broadcast protocol may be unable to meet this requirement. There have been several attempts to address this problem. Examples include proposals to broadcast RTS/CTS by way of multiple unicast [8], to implement a so-called request-to-broadcast/clear-to-broadcast (RTB/CTB) in [9], and to introduce out-of-band signalling using a busy tone in [10]. However, all of these proposals to improve reliability involve significant protocol overhead, or additional bandwidth (in case of out-of-band signalling).

In this paper, we investigate three schemes which improve the reliability of event messages with minimal protocol overhead, by retransmitting only event messages. In particular, we consider the following three alternate extensions to the basic

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protocol.

1) blind sequential retransmission,
2) blind batch retransmission,
3) retransmission based on piggybacked acknowledgements [11].

The former two schemes are proposed in this paper. They neither rely on any feedback from the receiving stations, nor introduce any additional protocol overhead. The two schemes are largely compatible with the Enhanced Distributed Channel Access (EDCA) extension to the DCF protocol of the DSRC standard [6], and require only that 802.11p permit packet bursts in the way that regular 802.11 does. In the sequential retransmission scheme, every event message is retransmitted a fixed number of times and, to mitigate against repeat collisions, the backoff before retransmissions uses a larger contention window than regular transmissions, although without binary backoff. This has similarities with the proposal in [12] for non-standard MAC protocols. In the batch retransmission scheme, the event message and a fixed number of copies of it are sent back-to-back in a batch, once the station has gained access to the channel. Like the sequential retransmission scheme, the batch scheme offers time diversity for an event message, but with the advantage of minimal additional delay. The last scheme, piggybacked acknowledgements, is based on the idea presented in [11] of each message carrying a list of identifiers of received messages to inform the sources of those messages of their successful reception. Conversely, the absence of a message identifier in the list is interpreted as a negative acknowledgement for the corresponding message, and triggers a retransmission. Many details missing from [11] are provided in this paper.

The contribution of this paper is threefold:

1) the proposal of two simple MAC protocol extensions that improve the reliability of delivering safety messages;
2) the provision of explicit technical details for the implementation of the piggybacked retransmission scheme;
3) performance evaluation and comparison of all the three retransmission schemes for a range of realistic parameter settings in CCA application using DSRC.

The remainder of this paper is organized as follows. In Section II, we provide an overview of DSRC challenges and standardization activities. We then propose the retransmission schemes to improve the reliability of event messages in Section III. In Section IV, we present simulation results to evaluate the proposed extensions. Finally, we conclude the paper in Section V.

## II. OVERVIEW OF THE DSRC PROTOCOL

The IEEE Wireless Access in Vehicular Environment (WAVE) project has developed the 802.11p standard [6] which specifies a MAC based on the standard 802.11 distributed coordination function (DCF) and a limited form of Enhanced Distributed Channel Access (EDCA), without the TXOP option for sending bursts of data. The results presented later in this paper suggest that it may be useful to retain the TXOP option. The DSRC spectrum contains a control channel reserved for control signals and safety critical messages. This paper is concerned with the latter use.

In the IEEE 802.11 DCF and EDCA, vehicles contend for the channel using Carrier Sense Multiple Access mechanism. Unlike regular 802.11, the case considered here does not have collision avoidance, either in the form of exponential backoff or RTS/CTS, as will be explained below.

CSMA works as follows. When a safety message is sent to the MAC layer for dispatch, the channel status is first observed. If the channel is silent for a guard period known as the distributed interframe space, DIFS, (or for EDCA, the arbitration interframe space, AIFS) then the message is transmitted on the air. If during that period of time, the channel instead becomes busy, then the access is deferred until the channel becomes idle again and a backoff process is initiated. During the backoff process, a discrete backoff counter is chosen uniformly in the range $[0, W-1]$, where $W$ is called the contention window. The backoff time counter is decremented by one at the end of each idle slot. It is frozen when a packet transmission is detected on the channel, and reactivated after the channel is sensed idle again for a guard period. The guard period is equal to a DIFS if the packet was received error-free, and equal to the extended interframe space, EIFS, if an error occurred. When the backoff counter reaches zero, the packet is sent at the next slot boundary. If two nodes are within transmission range of each other, their slots become synchronized. A collision occurs when the counters of two or more such nodes reach zero in the same slot. Collisions also occur when a receiver is within range of two transmitters, but those transmitters are not in range of each other, and hence cannot use carrier sensing. Such transmitting nodes are called *hidden nodes*. If the transmission from multiple hidden nodes overlap, the packets interfere and are discarded by the receiving node. This phenomena is called the *hidden terminal problem*.

In contrast to unicast communication, no ACK is sent after the successful reception of a data packet in the broadcast communication. So the sender is unaware of any packet collision and there is no retransmission and hence no binary backoff. This means that the transmission probability is unaffected by the collision probability, in contrast to regular 802.11 systems. The lack of retransmission greatly reduces reliability of broadcast communication. To make matters worse, RTS/CTS cannot be used to alleviate the hidden terminal problem, because it would require a handshaking exchange between sender and all the broadcast receivers. The mechanisms in the following section have been proposed to improve reliability in broadcast CSMA.

## III. RETRANSMISSION-BASED MAC PROTOCOL EXTENSIONS

Although many enhancements aiming to improve the performance of broadcasting in wireless ad hoc network have been proposed in the literature, most require out-of-band signalling or significant protocol overhead such as broadcasting virtual carrier sensing messages. In this section, we propose two schemes, namely sequential retransmission and batch retransmission, that enable performance improvement by retransmitting event messages multiple times without any additional protocol overhead. Since these schemes only retransmit event messages, which are rare, they do not impose an excessive increase in load. Note that these proposed protocols are compatible with the EDCA extension to the DCF protocol [13]. In addition, we examine the idea proposed in [11] to develop a so-called piggybacked scheme as a way of providing feedback without out-of-band signalling, but with some protocol overhead. In the following, we will describe each of the schemes in detail.

### A. *Sequential Retransmission*

In the sequential scheme (shown in Fig. 1(a)) the retransmissions are automatically carried out without feedback from the receivers, i.e., every event message is retransmitted a fixed number of times. Furthermore, to reduce repeat collisions, the backoff process executed between retransmissions uses a larger contention window than the initial one. The scheme is simple and compatible with the new standard, and hence can be easily deployed. When an emergency event occurs, instead of sending a single event message to the MAC layer, multiple copies are sent. The larger contention window before successive retransmission can be achieved by assigning one access category to the first copy and a different access category to the remaining copies using the EDCA mechanism of the DSRC standard.

Note that a similar approach using message retransmission has been proposed in [12] where the lifetime of the safety message is divided into slots and multiple copies are scheduled in different slots. However, the proposed protocol in [12] requires an extended MAC sublayer for scheduling packets in slots.

### B. *Batch Retransmission*

In the batch scheme (shown in Fig. 1(b)), multiple copies of an event messages are transmitted back-to-back with only small inter-frame spaces (SIFS). This can be achieved using the TxOP feature of EDCA mechanism. The only conditions under which all copies within a batch are corrupted are when it coincides with a batch of event messages from another node, or when the batch collides with multiple routine or event messages that are close together. The batch retransmission scheme has an advantage compared to the sequential scheme in that it reduces the number of collisions resulting in packet lost when there is only partial overlap of packets, reminiscent of the benefits of slotted Aloha over unslotted Aloha [14]. As a result, the loss probability will be considerably reduced. The delay experienced by retransmissions in this schemes is also expected to be negligible. Note that the TxOP option of the EDCA mechanism has been explicitly removed from ad hoc operation in the current version of the standard. We argue that its performance poses an attractive alternative for V2V system design and configuration, and that it should be allowed as it is in regular 802.11.

### C. *Piggybacked Retransmission*

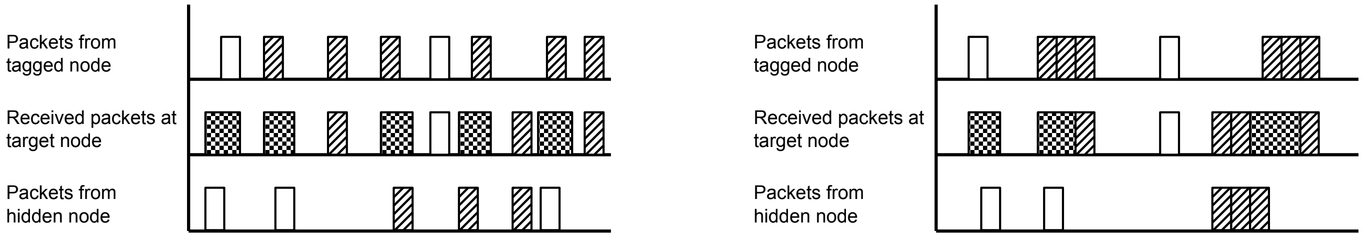
The piggybacked retransmission scheme (shown in Fig. 1(c)) is an extension to the piggybacked acknowledgement (PACK) protocol proposed in [11]. The basic idea is to place some additional information in each outgoing safety message such as the sender's position, the intended range of reception, a randomly generated message ID, and the IDs of the most recently received messages. Ideally each message ID should be unique in the local neighborhood, which can be achieved by choosing a sufficiently long ID. However, perfect uniqueness within the local neighborhood is not necessary as long as we can keep the chance of duplicate ID to a minimum. If duplicate ID exists, it will result in a false positive acknowledgement and reduce the packet reliability in case any of those packets were not received correctly.

In [11] the usefulness of the piggybacking was measured, but retransmission based on PACK was not discussed. As such, many details of how one can use PACK to recover a lost message and improve reliability are missing. We propose a specific algorithm for the retransmission of event messages based on information gained from PACK. The goal is to retransmit the packet if *any* of the intended recipients has not received it. However, it is not necessary to wait until feedback has been received from all intended recipients, since occasional spurious retransmissions are acceptable. The scheme is as follows. Upon receiving a piggybacked ACK from an node within its intended range, a sending node checks to see if the ID of the message it sent is among the received IDs. If the ID is absent, then the sending node flags that the message needs retransmission. To avoid consecutive collisions between hidden terminals, the retransmission is scheduled after a random time that is in the order of a packet transmission time. In the simulation, this time is chosen uniformly in the range of 0-5 ms. This waiting time is carried out independently of the backoff process. Note that the lifetime of each safety message is limited, and beyond that no retransmission is allowed. Also, if a newer message is generated before the retransmission, the older message is considered obsolete and the newer message is sent instead.

The benefit of the piggybacked scheme over batch and sequential scheme is that the expected number of transmission attempts per event message is lower. However, the list of IDs can constitute a considerable increase in packet overhead in dense network. For example, if there are 100 vehicles within the reception range, and each message ID is 2 bytes long, it will add an additional 200 bytes to the safety packet. The overhead could be reduced by either limiting the number of acknowledged messages or introducing a maximum allowable delay at the cost of reduced feedback accuracy.

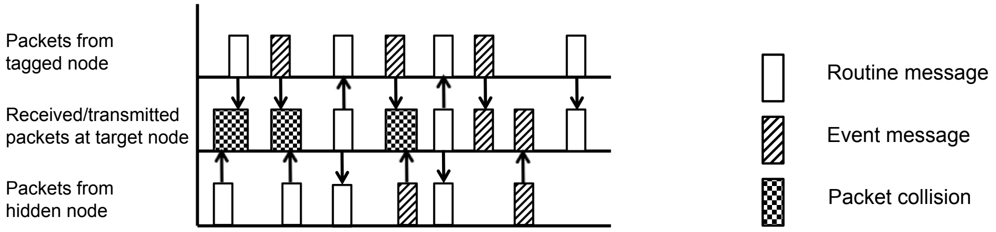
## IV. PERFORMANCE EVALUATION

In this section, we evaluate the three proposed retransmission schemes in terms of PDR and packet delay, using the ns-2



(a) Sequential retransmission scheme

(b) Batch retransmission scheme



(c) Piggybacked retransmission scheme

(d) Legends

Fig. 1. Retransmission-based extensions to IEEE 802.11 MAC protocol

simulator (version 2.30) [15]. To ensure compatibility with the existing MAC, the extension mechanisms were implemented on top of the existing MAC modules in ns2, except for the implementation of a larger contention window for retransmitted packets in the sequential scheme. This required changes to the MAC code for detection of retransmitted packets and an increasing contention window. This would not be needed in practice because these aspects can be performed in EDCA by modifying the access category parameters and assigning retransmitted packets a different access category.

We consider a highway scenario for performance evaluation of the proposed schemes. The highway consists of several lanes with vehicles moving in both directions. The width of the highway is considered to be comparatively much smaller than the transmission range, so that traveling vehicles can be approximated as residing on a line. In our simulation, we use a large radius circular topology to avoid any unwanted boundary effects. Vehicles are placed randomly on the circle according to a Poisson distribution; since the radius is large, all the vehicles within the transmission range of a tagged vehicle appear to be arrayed on a line.

To assess the effect of the packet traffic load on performance, we vary the vehicle density, $\beta$, to simulate different load conditions. We let $\beta$ range from 10 [vehicles/km], representing lightly loaded conditions, up to 100 [vehicles/km]. The latter is equivalent to free flowing vehicular traffic on a highway with 3 lanes in each direction, with vehicles traveling up to 100 [km/hr] while maintaining a 2 seconds gap between each other. We acknowledge that, in real traffic scenarios, higher traffic density may occur for example in traffic jam situation. However, in such situations, transmission range can be reduced to keep the number of vehicles within transmission range approximately unchanged.

A fixed packet size is considered for both routine and event messages. The piggybacked scheme incurs an additional overhead for feedback in the routine messages, as mentioned in subsection III-C. We fix this overhead to be 100 [bytes], which would be sufficient to accommodate a list of 2 byte message IDs for 50 recently received messages. The combined rate of all generated safety messages (routine and event) per vehicle is fixed at 10 [packets/second] while the proportion of event messages can be adjusted. The arrival of event messages to the MAC transmit buffer is assumed to follow a Poisson process. The routine messages, on the other hand, are generated using a quasi-periodic process as they are broadcasted regularly within a fixed interval. The process is quasi-periodic because the fixed arrival interval of the routine messages is restarted after a transmission of an event message. Also, in our simulation, a small jitter is added to the periodicity of the routine messages so as to avoid causing bursty channel traffic.

The number of retransmissions of event messages for the batch and sequential schemes is set to 3, while the maximum number of retransmissions for the piggybacked scheme is also set to 3. We assume idealized physical channels with propagation obeying a two-ray ground reflection model, without any fading or capture effect. All the DSRC related parameters are listed in Table I.

In the following we summarize our results and discuss the performance of different retransmission schemes. All the results are shown with 95% confidence interval.

In Figures 2–4, we plot the mean of the total delay observed by routine and event messages for all the three proposed extensions. The message delay using single transmission is also depicted on the same figures for comparison.

In Fig. 2, only 10% of the messages are event messages ($\alpha = 0.1$). We observe that the delays of routine messages for all the retransmission schemes are similar to that of the single transmission case and are below 1ms. There is a slight increase in delay with increased vehicle density due to increased contention in the channel. Also, the piggybacked scheme

TABLE I
DSRC SYSTEM PARAMETERS

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Contention window, $W$ | 32 | Transmission Range | 250 m |
| Slot size | 16 $\mu s$ | DIFS | 64 $\mu s$ |
| SIFS | 32 $\mu s$ | Ratio of event messages, $\alpha$ | 0.1, 0.2, 0.5 |
| Vehicle density, $\beta$ | 10–100 km$^{-1}$ | Data rate | 6 Mbps |
| Packet arrival rate | 10 s$^{-1}$ | Packet length | 200 bytes |

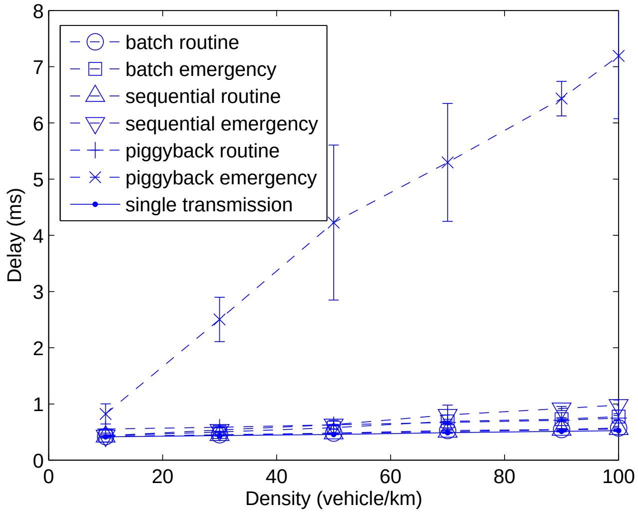


Fig. 2. Comparison of total delay for three proposed extensions with the single transmission scheme for $\alpha = 0.1$

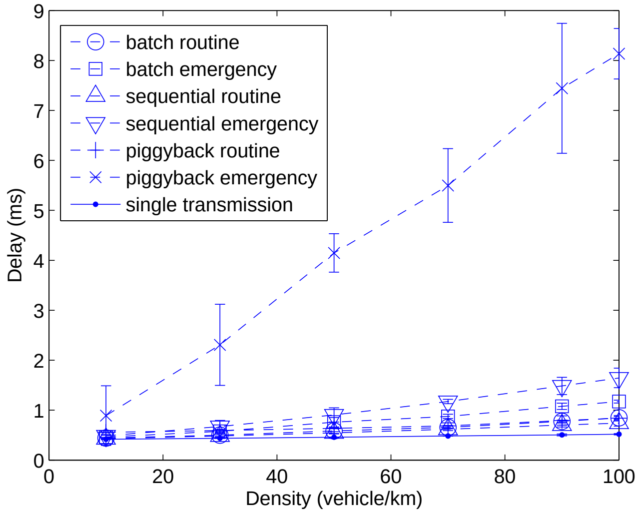


Fig. 4. Comparison of total delay for three proposed extensions with the single transmission scheme for $\alpha = 0.5$

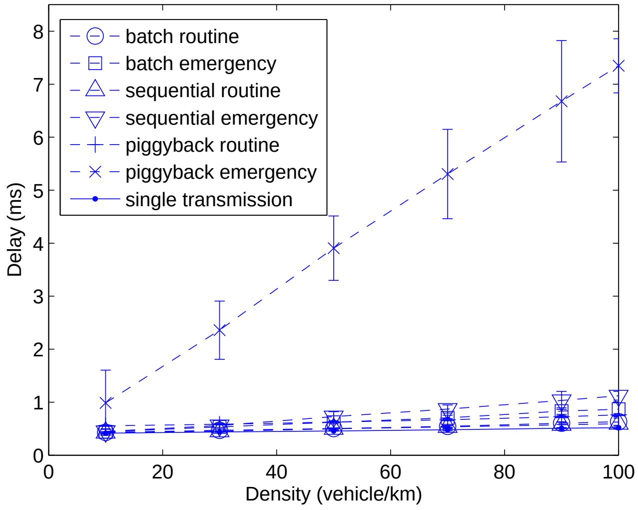


Fig. 3. Comparison of total delay for three proposed extensions with the single transmission scheme for $\alpha = 0.2$

incurs slightly more delay due to the feedback overhead. As we increase $\alpha$ to 0.2 in Fig. 3 and to 0.5 in Fig. 4, we observe an increase in the delay but it is still below 1ms.

For the event messages, however, the increase in delay is more pronounced, specially for the piggybacked scheme as can be observed in Figures 2–4. Recall that in the piggybacked scheme, the tagged node must wait for a packet reception to obtain feedback about its transmission, which may take several ms depending upon the vehicle density and packet rate. As such, with increased vehicle density and increased number of retransmissions for event messages, the delay increases up to 8ms for the $\alpha = 0.5$ case. We also observe an increase in delay for event messages in the batch and sequential schemes, but it is much smaller than that of the piggybacked scheme. The batch scheme has an advantage over the sequential scheme in terms of delay, as there is no backoff delay between the retransmitted packets.

In Figures 5–7, we compare the PDR between the three extensions and compare it to that of the single transmission scheme. We first discuss the PDR of the routine messages. In Fig. 5, we observe that the PDR for routine messages drops almost linearly with increased vehicle density. For the batch and sequential schemes, the PDR is close to the single transmission case, with the maximum difference being 5% in a dense traffic condition. Due to the overhead of feedback, the piggybacked scheme suffers more in terms of PDR. As we increase $\alpha$ to 0.2 in Fig. 6 and 0.5 in Fig. 7, we observe further degradation in PDR for all schemes. However, for the piggybacked scheme, the drop is smaller compared to that of other two schemes, because there are less retransmissions in the piggybacked scheme.

For event messages we can see the benefit of using retransmissions in Fig. 5. The PDR still drops with increased vehicle density, however the PDR is just below 90% even for

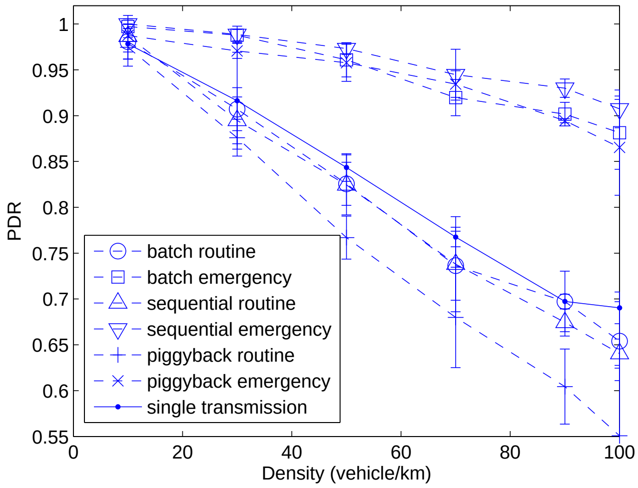


Fig. 5. Comparison of PDR for three proposed extensions with the single transmission scheme for $\alpha = 0.1$

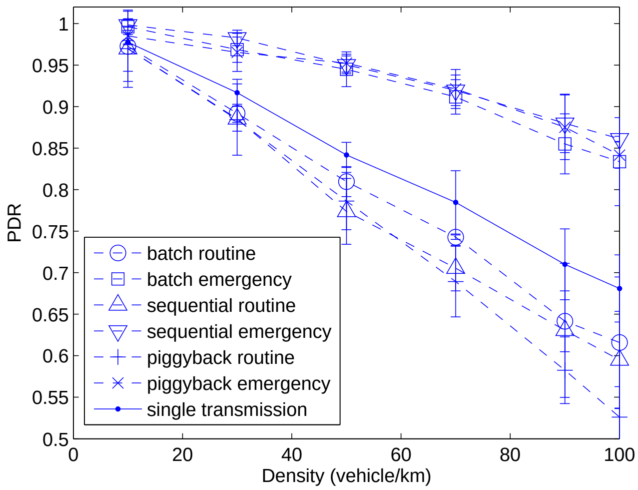


Fig. 6. Comparison of PDR for three proposed extensions with the single transmission scheme for $\alpha = 0.2$

the most dense traffic condition considered in this paper. The sequential scheme is slightly better than the other two schemes. We do not see, however, any advantage of the feedback in the piggybacked scheme in this scenario. In Fig. 6, we increase the ratio of event message to $\alpha = 0.2$. In this case, the PDR is still above 90% for vehicle density less than $\beta = 75$ [vehicles/km], but beyond that the PDR drops down to 85%. Also in Fig. 7, with $\alpha = 0.5$ the PDR quickly drops below 90% with increased vehicle density for batch and sequential scheme. The piggybacked scheme performs better in this case due to less retransmissions causing less network congestion under heavy traffic.

## V. CONCLUSION

In this paper, we have proposed two blind retransmission-based extensions to the medium access control (MAC) protocol and extended PACK protocol proposed in [11] to develop the piggybacked scheme. We have provided details for the implementation of these three schemes on top of the 802.11p standard [6] distributed coordination function (DCF) MAC protocol. By simulations we have demonstrated that these schemes can provide better than 90% PDR for event messages in diverse traffic condition. The improvement comes with the reduction in PDR for routine messages and increased delay for event messages. The feedback in the piggybacked scheme does not appear to provide significant improvement over the simple blind schemes due to the required overhead.

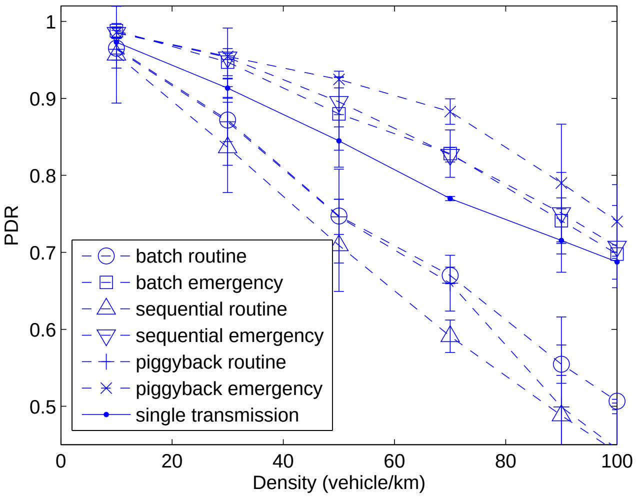


Fig. 7. Comparison of PDR for three proposed extensions with the single transmission scheme for $\alpha = 0.5$

The proposed schemes are suitable for free-flowing traffic, with moderately low vehicle densities. When congestion builds up, vehicle densities can become very high. This will be particularly problematic when traffic is banked up in one direction and moving fast in the other. Such cases will require techniques such as reducing the transmission range (transmission power) and the frequency of sending routine messages. We anticipate that the proposed schemes will be compatible with such techniques, but investigating that is left for further work.

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