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DENSITY-AWARE RATE ADAPTATION FOR VEHICLE SAFETY COMMUNICATIONS IN THE HIGHWAY ENVIRONMENT

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Abstract - The implementation of safety applications in vehicular ad hoc network (VANET) depends on the dissemination of safety related messages. A self-sorting MAC protocol is proposed for high-density scenarios. The protocol allows vehicles to sort with others in a collision-tolerance manner before data transmission. The vehicles establish a logic queue by the self-sorting process, and the queue is able to access the channel once the length reaches the set threshold. Vehicles in the queue will access the channel by time-division multiple access (TDMA) when the queue occupies the channel. A queue will compete for accessing the channel on behalf of all the nodes in the queue, which greatly alleviates the contention for access from all nodes. In contrast with completely random access, the slot a queue select to access the channel depends on the completion time of the self-sorting process. In this case, the queue accomplishing the self-sorting process first can avoid collisions with other queues since they are still in the self-sorting process. The performance of the proposed protocol is evaluated compared with other typical MAC protocols in VANET. The analysis and simulation results in highway and city scenarios show that the proposed protocol can significantly reduce packets loss and delay especially in dense scenarios.

1. INTRODUCTION

VEHICULAR ad hoc network is a self-organizing network aiming to improve the transportation safety and efficiency via various safety applications over vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. The safety application is the primary motivation for deploying vehicular communications, which depends on the dissemination of status messages containing velocity, position, etc. Vehicles broadcast their status messages every 100 ms for cooperative collision avoidance (CCA). The broadcast messages for safety applications are used for locating the vehicles in a collision threat or in blind spot and sending warnings when a collision or a sudden brake is detected.

The main challenge in VANET is the channel congestion in MAC layer in high density scenarios.

There are large amounts of devices sending their status messages in the transmission range, which will lead to serious packet collisions and increase the time delay. A suitable maximum delay requirement for the time-critical safety applications is 100 ms. It has been specified that the packet delivery ratio (PDR) should be not less than 90%.Simulationbased analysis show the impact of high density on latency and PDR.

The congestion control issues have been investigated extensively and various MAC protocols have been proposed to improve the performance of VANET. Since the safety related message are mainly transmitted by broadcast, there is no acknowledgement message for a successful reception. Thus, the sender is unable to adjust the contention window since it is unaware of any packet collisions. The authors which present a scheme for dynamic adaptation of transmission power and contention window based on the estimated local vehicle density and collision rates. The authors analyze the performance of carrier sense multiple access (CSMA)based broadcast networks in VANET by using tools from stochastic geometry. A theoretical analysis model is the performance of the distributed coordination function (DCF) MAC protocol in IEEE 802.11p, which is based on CSMA, and a retransmission algorithm is proposed to improve the reliability of the system. However, the extended analysis shows that the retransmission algorithm only works well under low density circumstances, but not suitable for high density cases since the extra packets of retransmission triggered by a failure transmission will aggravate the channel congestion.

A considerable number of cluster-based protocols have been proposed to improve the performance of VANET. A cluster-based scheme is presented in using the contention free MAC within a cluster and the contention-based IEEE 802.11 MAC among cluster-head vehicles. Each vehicle is equipped with two transceivers operating on different channels. The authors in present a distributed multichannel and mobility-aware cluster-based MAC (DMMAC) protocol, which allows vehicles to send updated status messages to the cluster head every 100 ms. The transmission range is decreased to make a compromise to guarantee the communication of all cluster members, which will hinder the performance of safety applications. It provide a taxonomy and comparative performance review for the existing cluster based protocols in VANET, and the main aspects of the clustering problem are discussed. The majority of cluster-based algorithms attempt to maintain the cluster topology through complicated control processes in a long time span, where the performance can be affected by the mobility of vehicles.

1.1 SELF-SORTING PROTOCOL

The self-sorting protocol consists of three steps for vehicles with packets to send: self-sorting, channel reservation and data transmission. There is no tight and universal synchronization, neither fixed structure of three phases in the proposed protocol. The transition of the phases is all trigged by particular situatione.g., once the length of a queue reaches the set threshold in the self-sorting process, the queue will start the channel reservation immediately, and if the queue occupies the channel successfully, members in the queue will transmit their data messages in the order of joining the queue. There is no need to maintain the structure, since the queue will be automatically dismissed after the last member finishes its data transmission.

1.2 Self-Sorting

Vehicles with a nonempty buffer aim to join in a self-sorting process or start a self-sorting process. When detecting the existence of a queue in the self-sorting process, the vehicle will compete to join the queue. Otherwise, the vehicle will start a self-sorting process by itself and become a temporary head of queue (QH) with the probability.

1.3 Channel Reservation

Queues will start the channel reservation process immediately when the length of the queue reaches the threshold t. The channel reservation mechanism is proposed to reduce the collisions caused by hidden terminals on such conditions: If quested within the range of each other's for data transmission finish the self-sorting process at the same time slot and start data transmission immediately, the data packets from different queues will conflict in the overlap area.

1.4.Data Transmission

The QH completing the channel reservation after sending the third reservation declaration tone will start the data transmission. First, the QH will send the data packet which consists of safety information and the sequence of the nodes in the queue. It is used to inform the nodes in the queue which miss the ACK message in the self-sorting process. The nodes in the queue will broadcast their data packets following the sequence from the head to the tail in TDMA. Then the channel is released, and nodes with packet to send will start a new self-sorting procedure and repeat the process above. Compared with existing slotted MAC protocols, only the data messages for safety applications are transmitted in the data transmission phase, and there is no extra control messages included in the packets, e.g., the allocation information of each slot in ALOHA and TDMA-based protocols aforementioned.

2. ANALYTICAL MODEL

2.1.System Model

We analyze the performance of the MAC protocol proposed in terms of the mean delay and the PDR, and the superiority in overhead is compared with the typical slotted protocols.

2.2.Probability of Successful Queuing

In this subsection, we construct a Markov chain to derive the probability of forming a queue successfully. In the self-sorting process, a smaller transmission range $R_l$is applied, and the transmission range of the declaration message is $2R_l$ to avoid overlap of adjacent queues. If a node has packet to send, it will become a temporary QH with the probability of P_1 by sending three short QH declaration messages in the range $[-2R_l, 2R_l]$.

2.3. Service Opportunity

In this subsection, we calculate the average service opportunity that a node can acquire for transmission after the self-sorting and the channel reservation process. If the node is in a queue which has successfully formed a queue with length of t, it has the opportunity to transmit its data packets in the transmission process. Otherwise, it just has to compete for the service opportunity in following processes.

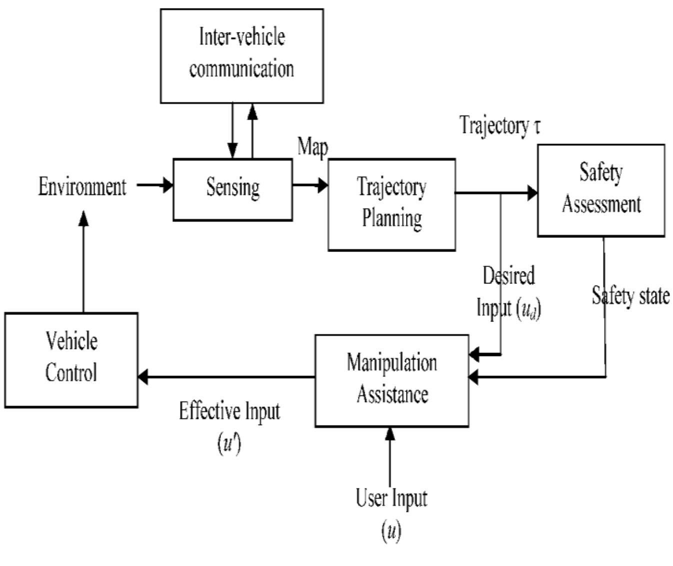
2.4.Implementation Overhead

We analyze the implementation overhead of the self-sorting protocol proposed in this paper, and it is compared with the typical slotted MAC protocols: TDMA-based and ALOHA based protocols, since they are the most relevant to this paper. For the fairness and the objectivity of the analysis, principles are established as follows:

i. The packet sizes except for the implementation overhead introduced by different protocols are the same.

ii. We define a parameter, the implementation efficiency (IE), to compare the overhead performance of different protocols. The IE is equal to the size of the payload of a packet divided by the total bits to transmit the packet.

Table -1: ARCHITECTURAL DIAGRAM

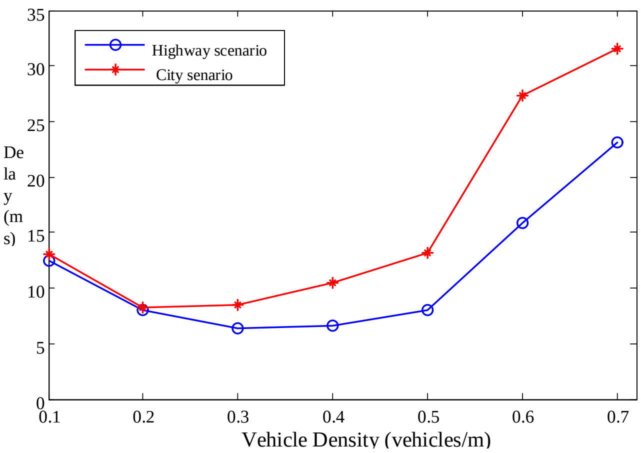


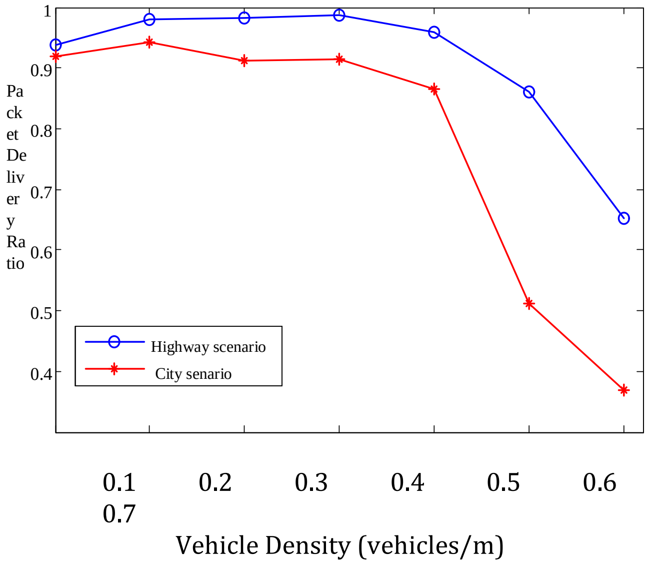
3. PERFORMANCE EVALUATION

To evaluate the proposed protocol in terms of delay and PDR, we conduct a series of analysis and simulations and present the results in this section. The simulations are based on highway and city scenarios. The performance of the proposed protocol is evaluated with different parameters configurations.

The highway scenario is based on a one-direction highway segment, with the velocity of vehicles ranges from 80-120 km/h, which is typical for highways. The city scenario consist of a horizontal street, a vertical street and four squares. The intersection of two streets is referred to as a junction area. Vehicles move into the junction area will choose possible direction with equal possibility. Vehicles located at the junction area can communicate with vehicles within transmission range on both streets. For a vehicle not at the junction area, it can only communicate with vehicles within transmission range on the same street due to the existence of city blocks.

However, in ultra-dense scenarios, the performance of the protocol proposed will degrade. It is because that the collisions become serious in the self-sorting process in ultra-dense scenarios. And after a queue successfully occupies the channel, the number of nodes in the queue which have the opportunity to transmit their data messages is constant whether in low density or high density situations, which means that the nodes will take more times to get a position in a queue. Therefore, the performance of the proposed protocol improves with the density first and then degrades. In spite of the degradation of performance in extremely dense scenarios, the self-sorting protocol shows the superiority compared with other MAC protocols in VANET.





Compare the performance of the self-sorting protocol in highway and city scenarios. It can be observed that the performance of the proposed protocol in highway scenario is better compared with the performance in city scenario at same vehicles density. The reason is that, in city scenario, vehicles not located at the junction area cannot receive the channel occupation messages from the other streets due to the obstruction of city blocks. If two queues located at two streets and they are both in the communication range of a vehicle in the junction area, packets from these two queues will collide if they transmit their packets at same time. The collisions lead to the performance degradation in city scenario. Nonetheless, the proposed protocol still shows performance advantages in both scenarios.

4. CONCLUSIONS

In this paper, a novel self-sorting MAC protocol is proposed taking advantage of the characteristic of high-density scenarios to improve the performance of high-density VANET, since the main challenge of VANET is to meet the communication requirements in dense situations. Vehicles form a queue by self-sorting like a "count off" process, and the queue reaching the specified length has the right to access the channel. The control messages for self-sorting are designed to be collision tolerable to reduce the collisions of data messages. The protocol changes the unordered random access into an ordered way. The variance of completion time of the self-sorting process introduces the time sequence naturally when queues compete for channel access. The analysis and simulation results evaluate the performance of the protocol in terms of delay and PDR. In addition, the overhead is less than the typical existing slotted MAC protocols, which have fixed structure and require continuous transmission of allocation information. Our future work will focus on adapting the protocol in various scenarios including more dynamic configurations optimization and support for heterogeneous requirements on delay and PDR.

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