The priority assignment of messages effects on delay performance in VANET

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Abstract. Low delay performance between neighbor vehicles in VANT need to an indepth research. In this paper, we conceived a novel priority assignment plan to reduce transmission delay. A priority was assigned to each message based on static and dynamic factors and size of the message. Dynamic scheduling sequence was carried out based on the messages priority assigned. The performance of proposed method was analysed in highway scenario on the average delay and waiting delay in queue. Simulation results are consistent with theoretical deriving. Therefore, low latency environments can be provided in Vehicular Ad-hoc Network using the novel plan.

1. Introduction
Vehicular Ad-hoc Network (VANET) has special characteristics such as high rate of topology change, high mobility of nodes, high nodes density, sharing the wireless channels, and frequently broken rout. Those special characteristics in VANET give rise to some challenges in data transferring and scheduling [1-4]. When the channels are saturated due to the increasing number of vehicles, congestion happens in the networks. In other words, when the vehicles send messages simultaneously in high density situations, the shared channels are easily congested. Congestion indeed leads to overload the Medium Access Control (MAC) channels, increases the packet loss and delay, and consequently decreases the performance of VANET. In this situation, safety messages (especially emergency messages) cannot be properly transmitted due to deficiency in the messages scheduling. It should be also noted that the scheduling in VANET is faced to some challenges because of sharing wireless communication channel and employing multi-channel technology with single-radio transceivers. Therefore, congestion should be controlled for enhancing the reliability of VANET [5-8].

In VANET, data traffic initiated from vehicles is expected to be random and bursty in nature. Vehicle-to-vehicle (V2V) communication is generally used in a multi-hop fashion in order to allow vehicles to connect to the out-of-transmission range road-side unit (RSU) [9]. In this way, bursty data flows are delivered to a remote vehicle through multi-hop transmission, which facilitates to support a broad range of applications including, e.g., car accident alert, road condition warning, video streaming,
Although multi-hop V2V communication can significantly improve the connectivity probability, the increases of end-to-end backlog and delay are difficult to avoid, which impact the quality of service (QoS) of the vehicular communication and may lead to inevitable network resources waste. From passengers’ perspective, end-to-end backlog and delay are the most critical factors and are arguably the most important service requirements that directly affect their experiences and satisfaction levels. Thus, it is necessary to have an in-depth understanding of the multi-hop end-to-end queueing performance of different types of data services. However, how to analyze the multi-hop end-to-end backlog queueing bound still remains as a challenging issue under the circumstances of the bursty data traffic characteristics and highly dynamic channel environment.

The multi-hop delay \cite{11} of the safety related messages is derived by multiplying the one-hop delay and the average hop count. One-hop delay is a period of time under which a packet is delivered from source to destination. The delay is composed of the processing delay \((D_{\text{proc}})\), queuing delay \((D_{\text{queue}})\), transmission delay \((D_{\text{trans}})\), and propagation delay \((D_{\text{prop}})\) \cite{12}. The processing delay is the time needed for extracting header of packets and executing various algorithms (e.g., routing algorithms, congestion control algorithms, etc.). The queuing delay is the waiting time of a packet in a queue before transferring. The transmission delay is the required time for transferring. The propagation delay is the required time for propagation of the packet. Thus:

\[
\text{Delay} = D_{\text{proc}} + D_{\text{queue}} + D_{\text{trans}} + D_{\text{prop}}.
\] (1)

The rest of the paper is organized as follows. Section II researches delay element. Section III proposes how to prioritize the messages in order to reduce delay time of packets transmission. Section IV analyses delay performance of transmission delay and queueing delay. Section V simulates the proposed strategy in the highway and discusses the obtained results.

2. Motivated Element

A delay control strategy in VANET is prioritizing messages in MAC layer. When the messages need access the channel, we can first define priority for the messages and then send them into different communication channels \cite{13}, \cite{14}. This method may serve more requests, reduce download delay, packet loss, and so on \cite{15}. Bouassida et al. \cite{16} first introduced a congestion control strategy that the priorities were assigned to messages based on utility and validity of messages, and speed of senders and receivers. Suthaputchakun et al. \cite{17} proposed a priority-based strategy using Enhanced Distributed Channel Access (EDCA) mechanism to increase safety in highway environments. EDCA can classify the message into four categories according to message urgency condition.

Generally, there are two types of congestion control mechanisms in networks: 1) open-loop mechanism without information feed and 2) closed-loop mechanism by information feed \cite{18}. Congestion control strategies in VANET include prioritizing and scheduling the messages in communication channels \cite{19}. Generally, the prioritizing and scheduling the messages is a very common open-loop congestion control strategy in communication channels \cite{20}. Some performance metrics are considered to increase efficiency of message transmission in VANET \cite{21}. In this paper, a delay control strategy is presented to reduce message delay. The paper mainly changes a few metrics such as weather condition and geography position.

3. Priority Assignment for the Message

In the priority assignment unit, priorities are assigned to the messages generated by applications in the vehicle or received from the other vehicles. Then, what time the message is transmitted is determined based on its priority assigned. The priority of each message is defined based on static and dynamic factors as well as size of message:

\[
\text{Priority}_{\text{Message}} = \frac{\text{Static}_{\text{Factor}} \times \text{Dynamic}_{\text{Factor}}}{\text{Message}_{\text{size}}}
\] (2)
PriorityMessage is directly proportional to StaticFactor and DynamicFactor. However, because the emergency and high priority safety messages have smaller size compared to the other messages, PriorityMessage is opposite proportional to MessageSize.

The StaticFactor is defined based on the content of messages and type of applications. StaticFactor for a message is considered to be 1, 3, 4, or 5 if the message belongs to PriorityService, PrioritySafety-Low, PriorityBeacon, or PriorityEmergency category, respectively [16]. MessageSize is considered to 1 or 100 if the message size is less than 500 byte or bigger than 500 byte. In the following, each category is detailedly defined as [22], [23].

In contrast of static factor defined based on the content of messages and type of applications, dynamic factor is defined based on circumstances of VANET. The metrics considered for calculating the dynamic factor are velocity of vehicles, usefulness of messages, validity of messages, directions of sender and receiver vehicles, weather condition, and geographic position. In the following, these metrics are described in details.

1. **Velocity metric (Vel):** This metric represents the relative speed of message sender that is defined based on the total coverage area of a vehicle traveling with velocity v during time dt (Figure 1) [24]:

\[
Vel = \frac{\pi \times R^2 + 2 \times R \times v \times dt}{\pi \times v^2}
\]  

(3)

where R is communication range, and v is average speed of vehicle in time dt. A higher priority should be assigned to the message with higher Vel metric.

![Fig. 1. Velocity metric (Vel).](image)

2. **Usefulness metric (Use):** This metric is defined according to the probability of message retransmissions by the neighbor vehicles. The usefulness is determined by the inverse of retransmissions:

\[
Use = \frac{1}{\text{retransmissions}}
\]  

(4)

3. **Validity metric (Val):** Validity metric is defined as the remaining time to the message deadline in real-time applications. The validity can be given by Equation (5) [24]:

\[
Val = \frac{\text{Remaining Time to the Deadline}}{\text{Transferring Time}}
\]  

(5)

Transferring Time in this equation, which is used for normalization, shows an estimated time to transfer message between sender and receiver vehicles.
4. **Distance metric (Dis)**: This metric is considered as a relative distance between message sender and receiver [24].

5. **Direction metric (Dir)**: direction metric shows that two vehicles (sender and receiver) are driving closer to each other (\(Dir=0\)) or they are driving away from each other (\(Dir=1\)) [24].

6. **Weather Conditions metric (WC)**: messages generated in severe weather condition should first be transferred.

7. **Geographic Position metric (GP)**: the priority of messages produced in rapid position is higher than that in ordinary position.

By combining Equations (3) to (5), the dynamic factor is calculated by Equation (6):

\[
\text{Dynamic Factor} = \begin{cases} 
\frac{\text{Vel} \times \text{Use}}{(\text{Val} + 1) \times \text{Dis} \times \text{WC} \times \text{GP}} & \text{dir} = 0 \\
\frac{\text{Vel} \times \text{Use} \times \text{Dis}}{(\text{Val} + 1) \times \text{WC} \times \text{GP}} & \text{dir} = 1 
\end{cases}
\]

Based on Equations (6) and (2), dynamic factor and consequently message priority are directly proportional to \(\text{Vel}\) and \(\text{Use}\) metrics. However, dynamic factor and message priority are opposite proportional to \(\text{Val}\), \(\text{WC}\), and \(\text{GP}\) metric. In this equation, \(\text{Val}\) metric is added to 1 to avoid ambiguous result when the validity is equal to zero. Equation (6) shows that dynamic factor is opposite proportional to \(\text{Dis}\) metric when \(\text{Dir}\) is equal to 0. However, dynamic factor is directly proportional to \(\text{Dis}\) when \(\text{Dir}\) is equal to 1. EDCA above mentioned is the default strategy of prioritizing in VANET [25], [26].

4. **Delay Performance Analysis**

Processing delay (nanosecond) is smaller than other delay factors (millisecond). So, the processing delay can be omitted in our computations. The propagation delay equals dividing distance between sender and receiver by the light speed. The propagation delay also can be omitted in our computations since the distance is much smaller than the light speed.

A. **Transmission delay Analysis**

Theoretically, transmission delay is decided by the average number of backoff slot and successful transmission time after using priority assignment. Transmission delay is calculated by Equation (7):

\[
D_{\text{trans}} = T_B + T_F + T_s 
\]

where \(T_B\) is back-off period, \(T_F\) is freezing back-off period, and \(T_s\) is successful transmission period.

If EDCA mechanism is applied to contest, \((T_B + T_F)\) can be computed on reference [27]. The reference analysed delay performance of IEEE 802.11p in saturation condition. To transmit a frame successfully, the average number of backoff slot that a station needs is

\[
E(X_i) = \frac{W + 1}{2} + d_i
\]

where \(d_i\) indicates the remaining frozen time before the backoff counter is reacted for states \((k, l)\) with \(k \geq 1\). The variable \(X_i\) \((i = 0, 1, 2, 3)\) represents the total number of backoff slots, which a frame encounters without considering the case when the counter freezes.

If we just consider the successful transmissions, the total number of slots which a frame encounters when the counter freezes is represented the random variable \(B_i\) \((i = 0, 1, 2, 3)\). The average frozen slot can get from

\[
E(B_i) = \frac{E(X_i)}{1 - p_i}
\]

where the probability \(p_i\) means that a station in backoff stage for the priority \(i\) class senses the channel busy.
Let $p_b$ denote the probability that the channel is busy. $p_s$ denotes the probability that a successful transmission occur in a slot time. The frame transmission delay of the priority $i$ class is average time of $\delta, (p_s/p_b)T_s$ and $T_s$ for an idle slot at state $(k, l)$ ($k>0$), a busy slot at states $(k, l)$ ($k>0$) and a successful transmission at states $(k, 0)$, respectively. $D_{trans}$ can be gotten from

$$D_{trans} = E(X_i)\delta + E(B_i)\frac{p_s}{p_b}T_s + T_s$$  \hspace{1cm} (10)$$

The second term in the formula (10) affects $D_{trans}$. When priority assignment unity is used, the term can be decreased until zero.

B. Queuing Delay Analysis

Link delay consists of queuing delay and channel contest delay. To reduce queuing delay, high priority messages will be immediately sent to the head of line before contest the channels. For this purpose, the message scheduling is conducted in two steps of static and dynamic scheduling.

![Static scheduling process](image)

Fig. 2. Static scheduling process.

In the static scheduling step, the messages are transferred to either control channel queue or service channel queue based on static factor. The method is similarly to EDCA mode. The messages with PriorityEmergency, PriorityBeacon, and PrioritySafety-Low priorities are transferred to control channel queue, and the messages with PriorityService-High and PriorityService-Low priorities are transferred to service channel queue. Figure 3 shows the static scheduling process in the message scheduling unit. In dynamic scheduling step, the packets in each queue are reordered based on their priorities when a new packet is entered to the queue. High priority message will be going to the head of line to waiting to contest the channel. This method is referred as “DySch”. The method by a long way reduces the time to queue because the message needn’t queue nearly.

The queuing delay is calculated by Equation (11):

$$D_{queue} = \frac{1}{\mu - \lambda} - \frac{1}{\lambda} \cdot \frac{Q_t \rho_Q}{1 - \rho_Q}$$ \hspace{1cm} (11)$$

where, $\rho$ is utilization which is equal to $\frac{\lambda}{\mu}$, where $\lambda$ and $\mu$ are packet arrival rate and packet service rate, respectively. $Q_t$ shows maximum queue length. If reschedule is used on priority assignment unity, $D_{queue}$ will be reduced substantially.

Since the priority was added on a message, the messages don’t queue and immediately will be sent to the head of line. Therefore, it does not take time for queuing to the head of line.

5. Simulation Result Discussions

For evaluating the performance of the proposed scheduling strategies in VANET, network simulators should be employed. In this paper, Network Simulator (NS) version 2.35 [28] were used for network simulation. Table 1 and Table 2 show the parameters used in the simulations of highway scenario. IEEE 802.11p was considered as the communication protocol. CSMA/CA strategy was also used as
transmission strategy in MAC layer. TwoRayGround was employed to model the propagation in highway scenario. The Poisson distribution was also used for generating the data traffic. A table-driven routing protocol like Destination-Sequenced Distance-Vector (DSDV) is assumed in simulations.

Table 1. Configuration parameters for simulation of the highway

| Parameters                  | Value   |
|-----------------------------|---------|
| Transmission rate           | 6 Mbps  |
| Bandwidth                   | 6 MHz   |
| Emergency message size      | 500 Bytes |
| MAC type                    | IEEE 802.11p |
| Propagation model           | TwoRayGround |
| Routing protocol            | DSDV    |
| Simulation time             | 200 s   |
| Simulation runs             | 20      |
| Back-off time slot length   | 13 μs   |

Table 2. EDCA parameters used in the CCH of WAVE

| Access category | CWmin | AIFSN |
|-----------------|-------|-------|
| AC₀             | 15    | 9     |
| AC₁             | 7     | 6     |
| AC₂             | 3     | 3     |
| AC₃             | 3     | 2     |

For more evaluation of the proposed strategy, the variation of the average delay with simulation time is investigated in Fig. 3. EDCA in IEEE 802.11p is the traditional channel contest method. So, average delay of DySch strategy compares with that of EDCA strategy. Here, the number of vehicles is assumed to be 50. Fig. 3 illustrates that by advancing the simulation time, the average delay of the packet transmission decreases for EDCA strategy and DySch strategy. However, using DySch strategy, the amount of reduction of average delay is higher than the EDCA strategy. In Fig. 3, it can be also seen that the average delay using DySch at simulation time 50 s is much lower than the EDCA strategy. It means using the proposed strategy, congestion is controlled before it occurs. Here, it should be emphasized that DySch strategy is open-loop strategy.

Fig. 3. Variation of the average delay with simulation time.
The impact of the message generation rate on average waiting delay in queue is evaluated for safety while congestion control is conducted using DySch. Fig. 4 illustrates that the average waiting delays in queue for safety messages are much low to 0.1~0.5 ms. A negligible delay for safety messages can be seen in Fig. 4. This result show that DySch transfers the safety messages in VANET without any significant waiting delay in queue.

6. Conclusion
In this paper, we proposed an improved DySch delay control strategy. DySch is distributed strategy. So, each vehicle independently prioritized and scheduled all the messages on its specification. The proposed strategy operated through two units: 1) priority assignment unit, and 2) message scheduling unit. In priority assignment unit, first, static and dynamic factors were calculated based on the content of messages and situation of vehicles, respectively. Then, a priority was assigned to each message based on static and dynamic factors and size of the message. The paper calculates the priority of messages by using new metric such as weather condition and geography position.

The performance of DySch strategy was analysed in highway scenario on the average delay and waiting delay in queue. Simulation results are consistent with theoretical deriving. Application of DySch strategy improved the performance of VANET by reducing the average delay. The average delay may highly be decreased on formula (12). Also, the queue delay can be nought since a packet can immediately arrive at head of line. So, the result showed that the applications of the strategy led to the lower waiting delay in queue. Therefore, more safe and reliable environments can be provided in VANET using DySch strategy.

In the future, some issues will be further researched. QoS model for VANET must be set up. QoS route and QoS MAC for VANET need further modified by tradition and new machine learning theories based on the model.

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