Dynamic Priority Assignment Algorithm Based on Multi-Elements in Vehicular Ad-Hoc Network

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Abstract. In Vehicular Ad-hoc Network, different messages have different degrees of urgency and have specific requirements on delay and reliability. In this paper, we propose a dynamic priority assignment algorithm based on multi-elements to adapt to the dynamic changes of vehicles and transmit messages in an accurately and orderly manner. A priority is assigned to each message based on static and dynamic factors and size of the message. After a detailed analysis of the allocated priorities, the results show that the algorithm we conceived can quickly and accurately allocate the priority for different kinds of messages based on the characteristics and requirements of them.

1. Introduction
Vehicular Ad-hoc Network (VANET) is a kind of centreless, multi-hop and self-organizing wireless network that adapts to moving vehicles proposed on the basis of Mobile Ad-hoc Networks (MANET)[1]. In VANET, vehicles communicate with each other via vehicle-mounted wireless communication devices and can obtain the status information of surrounding vehicles through the self-organizing network between vehicles without relying on the traffic management command center. Therefore, VANET can realize dynamic path planning and quickly detect potentially dangerous situations, so as to inform drivers to drive carefully and reduce the occurrence of safety accidents.

During transmission, different messages have different degrees of urgency and have specific requirements on delay and reliability. If the transmission priority of various messages is not reasonably allocated and transmitted in an orderly manner, the competition among messages can easily cause channel congestion[2]. Sharp increase of channel load will lead to broadcast storm, which will cause great data transmission delay and even packet loss. Therefore, it is necessary to design a reliable data priority allocation mechanism, in order to adapt to the dynamic changes of vehicles and transmit messages quickly, accurately and orderly.

Irfanullah et al.[3] proposed a priority-based content dissemination scheme. The content provided to vehicles are broadly classified into safety and non-safety. However, this scheme had too few elements to focus on when prioritizing messages. Jhihoon et al.[4] proposed a scheduling algorithm for emergency message dissemination (SAEMD) in vehicular ad hoc networks which aimed to minimize the delay of emergency message delivery to the closest vehicle. However, this scheme failed to consider the timeliness of the emergency message and the effective transmission range, which may cause a great delay in the transmission of non-secure messages. Sun et al.[5] proposed a priority-based security message transmission scheme in expressways. The priority classification method in the paper
referred to the message priority classification scheme in IEEE 802.11e, which satisfied the fast and reliable transmission of security messages. However, the non-security messages were not discussed in the article. Ding et al. [6] proposed a HetVNETs link scheduling algorithm in LLC protocol based on data priority and traffic flow density. However, the description of the priority classification in the article was too brief, and there was no example of which typical messages correspond to the four priorities. Li et al. [7] proposed a distributed TDMA-based scheme that controls the transmission range to improve the efficiency of BSM transmissions in VANET. However, when defining two kinds of perception areas, there was no specific range size. Gómez et al. [8] proposed the corresponding priority forwarding method of urgent data based on channel allocation. To some extent, the study ensured the priority transmission of emergency data, but it did not fully consider the hierarchical allocation of all data, so the priority transmission of different data was not well differentiated.

In order to prioritize transmission according to different data requirements, this paper proposes a dynamic priority assignment algorithm based on static and dynamic factors and size of the message. Unlike other studies, this paper subdivides security data into conventional security data and emergency security data and takes non-security data into consideration. At the same time, the priority of each message in the transmission process can change dynamically with time and distance, so that the transmission of the message can be controlled in an effective range of time and space.

2. 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. In this paper, the priority of each message is defined based on static and dynamic factors as well as size of message:

$$\text{Priority}_{\text{Message}} = \frac{\text{Static}_{\text{Factor}} \times \text{Dynamic}_{\text{Factor}}}{\text{Message}_{\text{size}}}$$

(1)

Priority$_{\text{Message}}$ is directly proportional to Static$_{\text{Factor}}$ and Dynamic$_{\text{Factor}}$. However, compared to the other messages, the sizes of the emergency and high priority security messages are usually smaller, so Priority$_{\text{Message}}$ is inversely proportional to Message$_{\text{size}}$.

2.1. Weight distribution of Static$_{\text{Factor}}$ and Message$_{\text{size}}$

The Static$_{\text{Factor}}$ is defined based on the content of messages and type of applications. Static$_{\text{Factor}}$ for a message is considered to be 1, 2, 3 if the message belongs to Priority$_{\text{Non-security data}}$, Priority$_{\text{Conventional-security data}}$, Priority$_{\text{Emergency-security data}}$ category, respectively. Emergency security data, which is sudden, consists of vehicle system failures, traffic accidents, road conditions such as maintenance sections, congested sections, etc. Conventional security data is the information that the vehicle sends to surrounding vehicles through periodic broadcasts, including its position, speed, direction, etc. Non-security data is mostly application service data, such as daily communication data, file sharing data, multimedia data, commercial advertisement push data, and so on. It is found that if the length of message transmitted between vehicles exceeds 500 bytes, it will be detrimental to transmission. So, Message$_{\text{size}}$ is considered to be 1 or 10 if the message size is less than 500 bytes or bigger than 500 bytes.

2.2. Weight Distribution of Dynamic$_{\text{Factor}}$

In contrast of Static$_{\text{Factor}}$, which is defined based on the content of messages and type of applications, Dynamic$_{\text{Factor}}$ is defined based on circumstances of VANET. The metrics considered for calculating the Dynamic$_{\text{Factor}}$ are velocity of vehicles, distance of sender and receiver vehicles, validity of messages, directions of sender and receiver vehicles, weather condition, and geographic position. Each message transmitted in VANET contains a five-tuple ($x_s$, $y_s$, $R_s$, $v_s$, Type$_s$, $T_s$, $D$), where ($x_s$, $y_s$)
represents the vehicle position and $R_s$ represents the communication radius of the vehicle, $v_s$ indicates the speed of the vehicle, $Type_s$ indicates the type of the transmitted message, $T_s$ indicates the effective time of the message and $D_s$ indicates the scope of the message. In the following paragraphs, these metrics are described in details.

2.2.1. *Velocity Metric (Vel)*: This metric can be extracted from the broadcast information between vehicles. If the message is security data, since the accident rate and its severity are directly proportional to the speed of the vehicle, in order to prevent traffic accidents or to avoid the expansion of the crisis, a higher priority should be assigned to the message with higher velocity. The normal speed of a vehicle is generally between 0 km/h and 100 km/h. The weight distribution is as follows:

$$\text{Vel} = \frac{v_s}{10}$$  \hspace{1cm} (2)

on the right-hand side, the units of all the variables and values are km/h. In order to limit the value of Vel to an appropriate size, we set the numerator to 10.

If the message is a non-security data, a higher priority is given to message that is slow relative to the sender vehicle, in order to increase the connection time so that to achieve the goal of high reliability. The reasons are that the doppler frequency shift increases with the increase of speed, vehicle route changes flexibly, D2D communication distance is limited and the size of non-security data for application service is usually very big, frequent communication link failure in the process of transmission situation will lead to great decrease of quality of service. So, the weight is assigned as:

$$\text{Vel} = \frac{10}{|v_r - v_s| + 0.5}$$  \hspace{1cm} (3)

where $v_r$ represents the speed of sender vehicle and $v_r$ represents the speed of receiver vehicle. On the right-hand side, the units of all the variables and values are km/h. Equation (3) shows that the weight of the velocity metric is inversely proportional to the relative speed of the two cars. In this equation, denominator is added to 0.5 to avoid ambiguous result when the speeds of the two cars are the same. In addition, the numerator is set to 10 in case the result is too small to calculate. In practice, the speed is usually an integer greater than 1, so the effect of 0.5 on the results is negligible.

2.2.2. *Distance Metric (Dis)*: This metric is considered as a relative distance between message sender and receiver:

$$D = \sqrt{(x_d - x_s)^2 + (y_d - y_s)^2}$$  \hspace{1cm} (4)

where $(x_s, y_s)$ represents the location of the sender and $(x_d, y_d)$ represents the location of the receiver. Distance metric should have the following characteristics:

- When the distance (Dis) $> \text{communication range (} R_s \text{)}$, the message cannot be sent, so the priority is 0.
- When the distance (Dis) $\leq \text{communication range (} R_s \text{)}$, the message priority is greater than 0 and decreases as the distance increases.

So, the weight is assigned as:

$$\text{Dis} = \begin{cases} \frac{R_s}{D}, & D \leq R_s \\ 0, & D > R_s \end{cases}$$  \hspace{1cm} (5)

2.2.3. *Direction Metric (Dir)*: Vehicles must be restricted to existing roads and follow relevant traffic rules, so their directions and paths are predictable. According to this, the following six models are proposed, as shown in Figure 1.
For emergency security data, when the sender vehicle encounters a dangerous situation, the weight may be assigned according to the necessity of notifying the target. In models 1, 3 and 5, the weight of direction metric is set to 3. In models 2, 4 and 6, the weight of direction metric is set to 0.

For other data, when the sender vehicle encounters a dangerous situation, the weight is assigned according to the relative distance between message sender and receiver. Among the six models, the relative distances in models 3 and 5 are getting smaller and smaller. At this time, the message should be transmitted first, so the weight is set to 2. However, the relative distances in models 1, 2, 4 and 6 are getting farther and farther, so the weight is set to 1.

2.2.4. Validity Metric (Val): Messages are real-time, and each type of message has its transmission delay limit, which is the effective time. At the same time, the scope of each message is limited, and the vehicle in the affected area can receive the message in time to avoid accidents. However, if the transmission of the message exceeds the actual scope of the event, this not only loses the validity of the information, but also wastes the scarce spectrum. Therefore, this paper proposes a scheme for dynamically assigning weights based on the time and space constraints of message transmission:

\[
Val = \alpha f(\Delta t) + \beta g(d) + \phi, \alpha \leq 0, \beta \leq 0
\]

where \(\Delta t\) represents the time interval which is required to receive the message from the sender to the receiver, \(d\) indicates the distance between the sending vehicle and the receiving vehicle, \(\phi\) represents initial priority, and \(\alpha\) and \(\beta\) represent priority attenuation factors of transmission time and distance, respectively. As time goes on and distance increases, the priority of the data will gradually decrease, but the attenuation of the security data is smaller than that of the non-security data. In order to study the generality of the problem, this paper sets:

\[
f(\Delta t) = \Delta t = t_d - t_s
\]

\[
g(d) = d = \sqrt{(x_d - x_s)^2 + (y_d - y_s)^2}
\]

\[
\phi = -\alpha T_s - \beta D_s
\]

where \(t_d\) is the reception time of the message, \(t_s\) is the time when the message was sent, \((x_s, y_s)\) represents the location of the sender and \((x_d, y_d)\) represents the location of the receiver, \(T_s\) indicates the
effective time of the message, and $D_s$ indicates the scope of the message. So, (6) can be converted into:

$$\text{Val} = \alpha \Delta t + \beta d - \alpha T_s - \beta D_s$$  \hspace{1cm} (10)

If $\text{Val} < 0$, the message will not be transmitted. Let $\text{Val} = 0$:

$$\Delta t_{\max} = T_s + \frac{\beta}{\alpha} (D_s - d)$$

$$d_{\max} = D_s + \frac{\alpha}{\beta} (T_s - \Delta t)$$  \hspace{1cm} (11)

When traffic density is low, it takes a long time for the vehicle to find the next hop route. It is likely that when the transmission time limit is reached, but the transmission distance is far less than the effective range. Since that $d < D_s$, substituting it into (7) can be obtained: $\Delta t_{\max} > T_s$. That is, the scheme can appropriately extend the transmission time and notify as many vehicles as possible within the effective range.

When the traffic density is high, the transmission delay between vehicles is very small, then the limit case is considered: $\Delta t = 0$, substituting it into (7) can be obtained: $d_{\max} = D_s + \frac{\alpha}{\beta} T_s$. That is, the maximum transmission distance is larger than the ideal range of $\frac{\alpha}{\beta} T_s$. In practice, the value of $\frac{\alpha}{\beta} T_s$ can be adjusted to reduce errors, thus reducing spectrum waste. However, considering the time limit only, the error is $\alpha T_s$. Obviously, the algorithm proposed in this paper produces a smaller error.

2.2.5. Weather Conditions Metric (WC): Messages generated in severer weather condition should first be transferred. In this paper, the weight of messages generated in severer weather condition is set to 2 and the weight of messages generated in normal weather condition is set to 1.

2.2.6. Geographic Position Metric (GP): The priority of messages produced in rapid position is higher than that in ordinary position. In this paper, the weight of messages produced in rapid position is set to 2 and the weight of messages produced in ordinary position is set to 1.

From what has been discussed above, the dynamic factor is calculated by:

$$\text{Dynamic Factor} = \frac{\text{Vel} \times \text{Dis} \times \text{Dir} \times \text{Val}}{\text{WC} \times \text{GP}}$$ \hspace{1cm} (12)

Based on (1) and (12), dynamic factor and consequently message priority are directly proportional to $\text{Vel}$, $\text{Dis}$, $\text{Dir}$ and $\text{Val}$ metrics. However, dynamic factor and message priority are opposite proportional to WC and GP metric. When the distance between vehicles exceeds the communication range, transmission is not necessary for directional reasons, or time and space limitations are exceeded, the message will not be sent, that is, dynamic factor and consequently message priority equal 0.

3. Numerical Analysis

In order to verify the feasibility of the message priority assignment model proposed in this paper, we analyse the priority of each message according to the proposed algorithm.

### Table 1. Validity metrics for different types of messages.

| Message Type               | $T_s$/s | $D_s$/km | $\alpha$ | $\beta$ | $\phi$ |
|---------------------------|---------|----------|----------|---------|--------|
| Non-security data         | 3       | 0.5      | -30      | -3      | 91.5   |
| Conventional-security data| 5       | 1        | -20      | -2      | 102    |
| Emergency-security data   | 12      | 4        | -10      | -1      | 124    |
Table 1 shows parameter settings for three common message types, such as effective transmission time ($T_e$), effective scope ($D_e$), priority attenuation factor for time and distance ($\alpha, \beta$), and initial priority of the messages ($\phi$). By substituting the data in the table into (10), we can get:

$$Val = \begin{cases} 
91.5 - 30\Delta t - 3d, & T_s = Non\text{-}security\ Data \\
102 - 20\Delta t - 2d, & T_s = Conventional\ -\ security\ Data \\
124 - 10\Delta t - d, & T_s = Emergency\ -\ security\ Data
\end{cases} \quad (13)$$

The results are consistent with theoretical expectations. Emergency security messages have the highest initial priority, followed by conventional security data and the lowest non-security data. As time goes on and distance increases, the priority of the data will gradually decrease, but the attenuation of the security data is smaller than that of the non-security data.

Table 2 shows the parameter settings and corresponding priority assignment of the six transmission messages. The results of priority assignment are consistent with the theoretical expectation. In general, emergency-security messages have the highest priority, followed by conventional-security messages, and non-security messages have the lowest priority.

Comparing the data in the first and second rows in Table 2, it can be seen that for emergency-security data, the priority is proportional to velocity and distance. At the same time, the direction of a vehicle also has a big impact on its priority. In models 1 and 3, both vehicles are getting closer, but the distance in model 3 is decreasing faster. Therefore, the data priority in model 3 should be higher. According to the algorithm proposed in this paper, the priority of model 1 is 5580 and that of model 3 is 9565. It clearly meets the transmission requirements.

Comparing the data in the first, third and fourth rows in Table 2, it is obvious that the emergency-security data has the highest priority. The priority difference of the first and third rows is much smaller than that of the first and fourth rows. This is because when the weather and geographical environment are very bad, it is easy to cause danger with a fast speed, so the priority of the messages should be increased, so as to remind the driver to pay more attention and drive more carefully.

The bottom two rows of data in Table 2 are non-security data. Since these messages typically have large message sizes and are less urgent than security data, their priorities are correspondingly lower. It should be noted that bad weather and rapid change of the geographical environment are very likely to cause linkage interrupt, which will greatly reduce the quality of service. Therefore, the priority of messages generated in these regions should be lower and transmission can be delayed appropriately until the vehicles move to the region with better environment.

### Table 2. Parameter settings and corresponding priority assignment of the six transmission messages

| Message Type                  | Message Size(byte) | Velocity (km/h) | Relative Velocity(km/h) | Distance (m) | Direction (model) | Initial Validity | Weather Condition | Geographical Position | Priority |
|------------------------------|--------------------|-----------------|-------------------------|--------------|-------------------|------------------|-------------------|----------------------|----------|
| Emergency-security Data      | 20                 | 40              | /                       | 80           | model 1           | 124              | Bad               | Ordinary            | 5580     |
| Emergency-security Data      | 20                 | 60              | /                       | 70           | model 3           | 124              | Good              | Rapid               | 9565     |
| Conventional-security Data   | 40                 | 50              | /                       | 80           | model 1           | 102              | Bad               | Rapid               | 5100     |
| Conventional-security Data   | 40                 | 70              | /                       | 70           | model 3           | 102              | Good              | Ordinary            | 4080     |
| Non-security Data            | 1000               | /               | 20                      | 80           | model 1           | 91.5             | Bad               | Ordinary            | 220      |
| Non-security Data            | 2000               | /               | 10                      | 70           | model 3           | 91.5             | Good              | Rapid               | 249      |
4. Conclusion
For the purpose of prioritizing different types of messages, this paper presents a dynamic priority assignment algorithm based on multi-elements in VANET. We have taken different types of messages into consideration, not just security messages and their priorities are assigned according to their characteristics and requirements. The numerical analysis of the allocated priorities verifies the feasibility of algorithm proposed in this paper.

No matter when and where, emergency security data always has the highest priority, followed by conventional security data, and non-security data has the lowest priority. At the same time, the priority of each message is not fixed and will gradually decrease with the passage of time and the increase of distance. In this way, the transmission of messages can be controlled within the effective time and range, and precious spectrum resources can be saved. The fast, accurate and orderly message priority assignment algorithm proposed in this paper can greatly improve the efficiency of vehicle message processing and reduce the waiting time required for message transmission.

5. Reference
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