Adaptive Link Parameter for V2X Communication in Predictable Channel

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Abstract. In the internet of vehicles (IoV), periodic beacon messages carry the function of traffic safety data interaction. However, when traffic density increases, these beacons will cause channel congestion. To solve the problem, an adaptive link parameters (ALP) assignment protocol based on predictable channel condition is proposed. The channel condition is estimated by traffic density, signal to interference plus noise ratio and channel busy ratio. According to the prediction of channel condition, beacon broadcast interval, power and modulation coding scheme are assigned. Congestion is avoided by controlling these link parameters. Performance of ALP is evaluated in the OMNET simulation platform. Results show that: 1. Packet delivery rate and latency are guaranteed in both congestion and idle channels. 2. Broadcast coverage and successfully received beacons number are improved in idle channel. 3. Channel utilization is high while avoiding channel congestion.

1. Introduction

Intelligent transportation system (ITS) is a new traffic system which can reduce accident rate effectively [1]. The internet of vehicles (IoV) is the foundation of ITS [2]. IoV defines safety beacon for proactive safety applications. On the basis of vehicle to everything (V2X) communication [3], vehicles in IoV broadcast beacons periodically to transmit traffic safety messages. When traffic density on the road reaches a certain scale, these periodic beacons will increase the load of wireless channel and lead to channel congestion. Therefore, research on congestion control in IoV is of great benefit to improve the performance of ITS.

Sommer designed the adaptive traffic beacon (ATB) protocol [4], which can adaptively adjust the beacon interval by collecting channel information, so as to reduce the impact of channel congestion and collision. Hu Rongna proposed a minimum maximum power-control evaluation of transmission reliability (MMPETR) algorithm [5]. The minimum transmission power and the maximum transmission power for successful reception were studied. Chen Shuqun presented a power control method which using different channel busy ratio thresholds to adjust transmission power adaptively [6]. These methods can ease congestion by controlling power or interval, but they do not consider these two or more parameters comprehensively.

In this paper, we show that this complexity can be handled using an adaptive link parameter (ALP) assignment protocol. ALP is designed to control channel congestion by assigning broadcast interval, power and modulation coding scheme (MCS). This protocol includes two parts as showed below:

1) Channel prediction model: predict channel quality by calculating channel busy ratio, signal transmission quality and next interval congestion probability.
2) Link parameter assignment method: assign broadcast interval and power to avoid congestion based on channel prediction, and adjust MCS to ensure packet delivery rate (PDR) and latency.

2. Adaptive link parameter

In the section, we outline the system architecture of ALP and introduce the mechanisms for channel quality prediction and for link parameter assignment.

2.1. Channel Prediction Model

The spatial topology of IoV communication channel has the following two characteristics: First, the geometric topological shape of the road, which limits the range and trend of vehicle movement, has predictability. Second, the vehicle communication terminal has faster mobility than the pedestrian in the general mobile cellular network, and the channel environment has the characteristics of rapid change. Therefore, the characteristics of channel predictability and time-varying should be fully considered in ITS congestion control.

Channel prediction model is based on the communication between road side units (RSU). The following three complementary parameters are calculated to evaluate channel quality:

1) Channel busy ratio (CBR) [6]:

\[
CBR = \sum_{i=1}^{n} k_i / n, k_i \in \{0, 1\},
\]

Check whether the channel is busy before each transmission. If busy \( k \) is 1, if idle \( k \) is 0.

2) Signal transmission quality \((STQ)\):

\[
STQ = \max \{1 - \frac{SINR}{SINR_{\text{max}}}; 0\},
\]

Signal to interference plus noise ratio \((SINR)\) is used to evaluate \(STQ\), and we configured a maximum \(SINR\) (30dB).

3) Next interval congestion probability \((NICP)\) [4]:

\[
NICP = \min \left\{ \frac{\text{vehicles}_{\text{prediction}}}{\text{vehicles}_{\text{max}}} : 1 \right\},
\]

\(\text{vehicles}_{\text{prediction}}\) is the prediction of vehicle density. \(\text{vehicles}_{\text{max}}\) is 200 vehicles/km.

Finally, the channel quality \(Q_c\) can be calculated as follows:

\[
Q_c = \frac{NICP + w_c \times (STQ + CBR)}{1 + w_c},
\]

We set factor \(w_c\) greater than 2 to show that \(STQ\) and \(CBR\) have more influence on \(Q_c\). \(Q_c\) close to zero indicates good channel quality.

2.2. Link parameter Assignment Method

On the basis of channel prediction model, the following communication link parameters are allocated:

1) Broadcast interval \(I_b\):

\[
I_b = \max \{I_{\min}; Q \},
\]

The minimum \(I_b\) is \(I_{\min} (0.05s)\). \(I_b\) ranges from 0.05s to 1s.

2) Transmission power \(P_t\):

\[
P_t = \min \{P_{\min} e^{\varphi}; P_{\max}\},
\]

The minimum \(P_t\) is \(P_{\min} (17\text{dBm})\), and the maximum \(P_t\) is \(P_{\max} (33\text{dBm})\).

3) Modulation coding scheme \(MCS\): As shown in Table 1, \(MCS\) is assigned in different ranges.
Table 1. The range of $Q_c$ corresponding to different MCS.

| MCS | OFDM modulation | Coding rate | Range   | MCS | OFDM modulation | Coding rate | Range   |
|-----|-----------------|-------------|---------|-----|-----------------|-------------|---------|
| 0   | BPSK            | 1/2         | 0.28~1  | 4   | 16QAM           | 1/2         | 0.04~0.11|
| 1   | BPSK            | 3/4         | 0.22~0.28| 5   | 16QAM           | 3/4         | 0.01~0.04|
| 2   | QPSK            | 1/2         | 0.16~0.22| 6   | 64QAM           | 2/3         | 0.004~0.01|
| 3   | QPSK            | 3/4         | 0.11~0.16| 7   | 64QAM           | 3/4         | <0.004  |

2.3. Example of the ALP Protocol

ALP is a collaborative optimization protocol of vehicle-to-vehicle and vehicle-to-infrastructure, which is based on channel prediction model and controlled by link parameter assignment method. The specific implementation is shown in Fig 1:

1) In the last time cycle (10s), RSUs collect beacons broadcasted by on board units (OBU) to count the channel busy times, detect $SINR$ and collect vehicle position change information.
2) $CBR$, $STQ$ and $NICP$ are evaluated by channel prediction model to estimate $Q_c$.
3) Allocate broadcast parameters for the next cycle to avoid congestion and ensure the transmission quality.

![Figure 1. Flow chart of ALP.](image)

3. Simulation verifications of ALP

We use veins [7] framework to establish the vehicle networking communication model in OMNET++ [8] network simulation platform based on sumo [9]. The specific parameters are shown in Table 2.

Table 2. Common simulation parameters.

| Parameter             | Value                                      | Parameter        | Value                      |
|-----------------------|--------------------------------------------|------------------|----------------------------|
| Beacon interval       | 0.05~1s                                    | Fading model     | Nakagami-m                 |
| Transmission power    | 17~33dBm (50mW~2000mW)                     | Receiver sensitivity | -110dBm                  |
| Modulation            | BPSK, QPSK, 16QAM, 64QAM                   | Vehicle length   | 5m                         |
| Coding mode           | Convolutional code                         | Acceleration     | -4.5~2.6m/s²              |
| Coding rate           | 1/2, 2/3, 3/4                             | Maximum speed    | 14m/s                      |
| Date rate             | 6Mbps                                      | Simulation time  | 0.5h                       |
As shown in Fig.2:

1) When the channel is idle, increasing the transmission power can increase the power of the received signal. PDR can be guaranteed by improving the signal to noise ratio. When the channel is congested, increasing the transmission power will cause more interference. At this time, reducing the transmission power can reduce the communication range, thus reducing the number of nodes in the communication range to alleviate congestion.

2) The smaller the broadcast interval, the more packets lost due to interference. In the congested channel environment, increasing the broadcast interval can alleviate the impact of congestion on PDR.

3) Through the adaptive allocation of link parameters by ALP, the influence of interference and congestion on PDR is effectively solved, and the PDR is guaranteed to be higher than 90%.

![Figure 2. PDR distribution of fixed parameter method and ALP.](image)

Fig.3 shows that: as the number of vehicles increases, the probability of busy channel increases. ALP dynamically adjusts the interval to reduce the delay caused by waiting.

In Fig.4, comparing the channel utilization of ALP and traditional method, ALP has higher utilization when vehicle density is low, and does not increase the channel load when vehicle density is high.

![Figure 3. Latency comparison.](image)

![Figure 4. Channel utilization comparison.](image)
4. Conclusion

We presented a congestion control protocol in IoV, Adaptive Link Parameter (ALP), which can avoid congestion and improve communication quality by controlling link parameters. ALP is based on predictable channel quality. The communication between RSUs and OBUs is fully utilized to collect traffic and channel information. Allocation method is the core of ALP. Broadcast interval and transmission power are allocated to ease channel congestion, and modulation coding scheme is considered to improve transmission quality. In addition, ALP has higher channel utilization. Last but not the least, we will continue to improve ALP in more parameters and better strategies.

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