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On-Road Feature Detection and Fountain-Coded Data Dissemination in Vehicular Ad-hoc Networks

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Abstract—**Within the smart city framework, information dissemination in vehicular ad-hoc networks (VANET) is attracting considerable interest in both the research community and industry. Efficient data dissemination has long been a problem in ad-hoc networks. In VANET, the problem is even more challenging given the high mobility of vehicles, high density of buildings, and intermittent network connectivity. Realistic modelling of the mobility patterns of vehicles (instead of random models like Random Waypoint or Manhattan Models in previous works) is important for accurate performance evaluation. In this paper, the transmission of on-road feature detection data (images or videos) with fountain code in VANET is studied. Specifically, we propose a robust license plate detection module and applied fountain coding in the application layer to largely reduce the average transmission delay of multi-media data. The proposed system are rigorously evaluated under a semi-realistic simulation of an inter-bus communication network in the Mong Kok urban district in Hong Kong with the consideration of real-world traffic parameters, such as different traffic density at different hours of a day and building obstacles. Specifically, we find that fountain coded data dissemination shows better performance boost in more realistic signal propagation model in urban areas. In practice, the proposed system can be applied to bus lane occupancy control. For example, when a vehicle illegally occupies the bus lane, buses nearby can help recognize the vehicle and transmit the detected results through the VANET to patrol cars for the enforcement.**

Index Terms—**VANET, On-Road Feature Detection, Fountain Code**

I. Introduction

The construction speed of road infrastructure is far less than the growth rate of vehicles in cities. Traffic problems, such as traffic accident, congestion and vehicle emission, are getting more and more serious. The concept of Intelligent Transportation System (ITS) under the smart city framework aims to alleviate and minimize these issues. Vehicular Ad-hoc Network (VANET) as being one of the key ITS components, which provides vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications capabilities, can connect with generic traffic monitoring systems and be equipped with efficient data dissemination methodologies for building up a safer and smarter transportation system.

There has been a tendency of growing interest in data dissemination through VANET for both safety-related and infotainment services. Among all those VANET applications, a popular one is on-road feature recognition or more specifically, License Plate Recognition (LPR). For example, LPR can be exploited to enforce bus lane occupancy control. The detected sensor data can also be communicated or distributed among vehicles in the VANET with fountain coding techniques for enhancing various kinds of decision making, control and management. Nevertheless, there are a number of difficulties in the design and implementation of such system. On one hand, the communication performance in VANET depends highly on the traffic flow, mobility patterns of vehicles as well as building obstacles. On the other hand, the LPR-based data dissemination with fountain code poses a challenge at different time of a day due to the illumination fluctuation in the environment for robust on-road feature detection, and the different density of traffic flow under peak or non-peak hours for efficient data dissemination. In this paper, under a highly realistic traffic model constructed based on real-world empirical data, fountain coding is exploited in VANET with the consideration of practical transport factors to enhance the dissemination efficiency of multi-media data from the feature detection module. Moreover, we evaluated the transmission scheme with the building propagation loss model under the Mong Kok scenario, which shows more realistic network performance results compared to the conventional two-ray ground model.

As a subclass of Mobile Ad-hoc Network (MANET), VANET characterizes high node mobility and rapidly changing topology [1]. This motivates a large number of researches in the area of VANET. However, many of the previous works did not capture vehicle motion accurately. For example, most of them [2-4] assume random mobility models (e.g., random waypoint or Manhattan models), which is obviously not sufficient to characterize the practical movements of vehicles in transportation networks. Therefore, in this paper, mobility traces are generated with professional traffic simulator Simulation of Urban Mobility (SUMO) [5], which can better reflect the realistic vehicular traffic in real road topology of the Mong Kok district in Hong Kong. In addition, since VANET is the communication carrier within the transport network, efficient data dissemination is always the key challenge. However, traditional protocols such as Transmission Control Protocol (TCP) require frequently acknowledging each block of messages and maintaining the transmission sequence to make sure the transmission reliability, which is not practical at all. To achieve better network performance, fountain code has been proposed in VANET in [6-8]. Nevertheless, the single linear highway scenario considered in these previous works cannot reflect the condition in central urban areas. Therefore, we apply fountain coding to VANET with more practical vehicular traces in this paper. Besides, [9] proposed an empirical shadowing model for the signal attenuation of building obstacles in Line-of-sight (LoS) conditions. In our work, we consider the building propagation loss effect when the inter-vehicle communication links are being blocked by obstacles. Thus, the communication situation is judged based on both the dynamic vehicle positions and building locations in the Mong Kok scenario. Upon these settings, Luby Transform (LT) code [10] is implemented in the VANET's application layer and encoded packet slices are transmitted through the User Datagram Protocol (UDP). Synthetic mobility traces generated by SUMO is imported into the Network Simulator 3 (NS-3) [11] for evaluating the performance of the fountain-coded data dissemination in 802.11p-based VANETs with the consideration of realistic building obstacles.

For the on-road feature detection application, an accurate license plate localization algorithm (within an image) plays an important role in LPR. In this paper, we propose a two-phase approach with the HSV (Hue, Saturation, Value) color segmentation method as the first phase. To compensate the failure detection reasoned by illumination variation, the gray-scale vertical edge detection follows. It is verified that such hybrid approach can enhance the overall license plate detection rate and robust for different lighting conditions. Overall, the major contributions of this paper are three-fold:

1. We develop a robust LPR algorithm with a successful location rate of 91.90%, which improves the gray-scale method by more than 20%;
2. We propose a fountain coding based dissemination protocol for LPR-related data. Under practical VANET scenario, the protocol can achieve an average throughput of 62 times faster than the generic TCP and more than 28% faster than UDP; and
3. We synthesize a highly reliable traffic model in a densely populated urban environment in Hong Kong and propose a building propagation loss model to evaluate the data dissemination protocol through a semi-realistic joint transport and communication simulation. Under various traffic conditions, the building loss model shows more realistic network performance compared to the traditional two-ray ground model.

II. PROPOSED METHODOLOGIES

A. System architecture

In this section, we present a framework for disseminating traffic monitoring data throughout the transportation network to facilitate the construction of a smart city. Four major parts are proposed in the system: they are i) On-road feature detection of LP; ii) multi-media packet fountain coding; iii) information dissemination based on DSRC (Dedicated Short Range Communications); and iv) inter-vehicle connectivity modelling in a semi-realistic scenario.

Fig.1 illustrates the system structure. The on-road feature detection block consists of two LPR algorithms, making use of colour information or gray-scale vertical edges for detection. Furthermore, the feature detection related data processing with the fountain coding module, including the encoder and decoder, makes it possible to reduce the average transmission delay. In addition, the semi-realistic scenario modelled in this study is rigorously constrained by the road topology and traffic control mechanisms (such as the presences of bus stops and traffic lights) to better reflect the reality. Finally, the VANET short-range communication protocol (IEEE 802.11p), is enabled in all vehicular nodes for the analysis and evaluation of inter-vehicle communications.

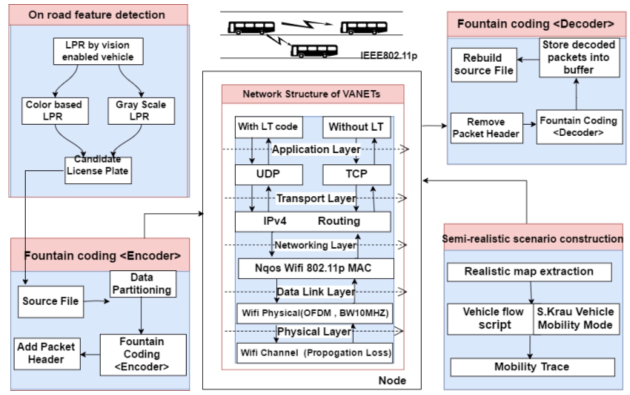


Fig. 1. System structure.

B. Data dissemination with fountain code

Fountain code is a type of rateless code. Without caring the transmission sequence, this coding method can adapt to high packet loss rate channel, such as wireless communications under the VANET scenario.

1) Encoding of LT code

To encode a sparse-graph LT code, the degree distribution function is a key factor. This helps form an encoded packet from one-to-many original packet(s) with the operation of exclusive-or (XOR). The overall coding steps are described below:

- From all source packets, select degree-d packets using the Random Number Generator (RNG);
- Conduct module 2 bitwise sum of these source packets to generate an encode packet.

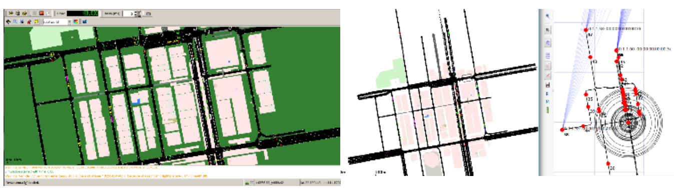
Specifically, the RNG plays an important role to ensure all the original packets get equal probability to be selected and encoded together. Another important element is the encode key, also known as the seed. Generated by the Pseudo RNG in the coding step 1 above, we pack the seed into the header of each packet. Unlike directly including all the relationship (neighbours) between the original packets and encoded packets, these encode keys help recover all the neighbours and degrees at the decoder side with the same RNG used in the encoder. In another word, the encode keys facilitate the generation of the relationship between the original packets and encoded packets.

2) Decoding of LT code

On the decoder side, the source-file length and seed information are being read from each received packet header. The Belief Propagation (BP) algorithm is employed for decoding. This is an iterative process aims to decode degree one packet first and remove the relationship between this packet and other connected packet(s), until decoding finished successfully. Nevertheless, as a type of random generation code, decoding fails when there's no degree one packet received. When we receive $N = (1+\varepsilon)K$ packets, K is the number of source packets and ε represents the overhead. In practice, the issue of decoding failure can be simply resolved by increasing the overhead. In our experiment, we transmitted 10,529 packets (10.5 Mb video) in total and vary the overhead from 0.01 to 0.11 for the reception of 100 encoded packets. We find that we can realize 100% successful transmission with an overhead of about 11%.

C. Mobility modelling in VANET

Since mobility in VANET is a variable of both time and space, to characterize vehicle motions, most previous works assume random mobility models, which are obviously not sufficient. In this paper, we consider VANET mobility with the limitation of various geographical factors using the microscopic traffic simulator—SUMO. As shown in Fig. 2, after extracting the real road topology of the Mong Kok urban district in Hong Kong, we further consider the configuration of fixed bus routes, the dwell time of buses and the traffic signal duration are configured according to empirical data in the scenario. With our final VANET as illustrated in Fig. 2a, the mobility traces generated from SUMO are then imported into Network Simulator 3 (NS-3) for evaluating the performance of inter-vehicle communications with fountain code based data dissemination in Fig. 2b.

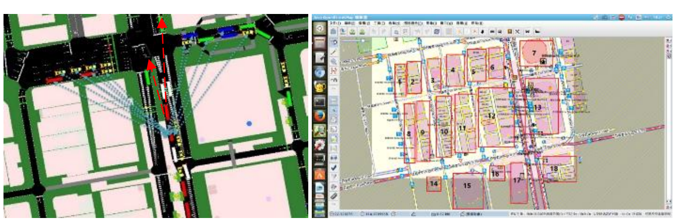


(a) (b)

Fig. 2. VANET scenario construction in both SUMO and NS-3

D. Inter-vehicle Communications

To further analyse and evaluate the performance of the proposed data dissemination method with practical VANET scenario, we simulated the inter-bus communications in NS-3. This discrete-event network simulator as described in [11] models all the communication network elements, and help establish the VANET architecture based on the synthetic mobility traces from SUMO. In our experiment, we intended to select buses as the communicating nodes as structured mobility patterns made them ideal as communicating hubs for forwarding various traffic monitoring information.



(a) (b)

Fig. 3. An obstacle model for VANETs.

In our simulation, IEEE 802.11p that operates on the 5.9 GHz band is enabled on bus nodes. The major features of its microwave are high frequency, short wavelength and travel in more or less a straight line, which also determines the weak diffraction ability. Thus, in the urban scene, the communication between vehicles in a Non-Line-of-Sight (NLoS) distance can be affected by the obstacles, such as buildings (Fig. 3a), which can lead to the intermittent network connectivity. Therefore, a building penetration loss model based on the building obstacles of the Mong Kok district proposed in Fig. 3b.

In our proposed method in (5), the propagation loss in the LoS condition is calculated by the ITU-R 1411 LoS model in NS-3. While the wall penetration loss (2×7(dB) concrete wall penetration loss) is considered when the signal transmission needs to go through a building with two external wall loss in the NLoS condition.

$$L_{V2V} = \begin{cases} \text{ITU}, & \text{LoS} \\ \text{ITU} + 2 \times \text{Wall\_Loss}, & \text{NLoS} \end{cases} \quad (5)$$

Therefore, to determine whether the link got NLoS, the method we propose with the pseudo code below:

TABLE I. PSEUDO CODE TO DETERMINE THE LOS AND NLOS CONDITIONS

```
▶ Get the position of Vehicle_a(x_1, y_1) and Vehicle_b(x_2, y_2);
for (α = 0.1; α < 1; α = α + 0.1)
    {Position_c(x, y)=( (αx_1 + (1 − α)x_2), (αy_1 + (1 − α)y_2));
▶ Acquire the Mong Kok building boundaries;
    if (c(x, y) drops into the building boundaries)
        { loss model = NLoS; L_V2V = ITU + 2 × Wall_Loss;}
        else {break;} }  loss model = LoS; L_V2V = ITU;
```

E. On Road Detection of License Plate

LPR is one of the popular ITS applications. For this reason, to achieve a robust and accurate detection result, we consider in this paper two LPR systems, namely the HSV colour segmentation method and gray scale vertical edge detection method. Under the same image recognition database randomly acquired in Hong Kong, we classified all database images into different categories (e.g., based on time of the day, orientation, image clarity, etc.). With a convincible comparison of the limitations of these methods, we conclude that these two systems can be integrated to form a two-phase LPR system.

1) Colour segmentation method

Generally speaking, in day time, the illumination is enough and the lighting condition on LP is uniformly distributed. Therefore, the colour-segmentation method is proposed and can be achieved within four steps as shown in Fig. 4.

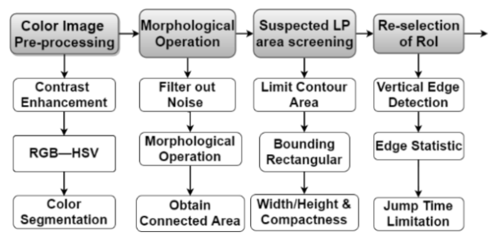


Fig. 4. Colour segmentation system.

A range of yellow pixels (the LP's background colour of vehicles in Hong Kong) within the HSV domain are segmented out through pre-processing. The morphological operation followed by to combine broken areas into connected regions. Subsequently, suspected LP areas limited by the width-to-height ratio of the bounding box of these connected regions are being screened. However, some noisy regions within the same colour domain, such as billboard and road lane lines, may still exist, and this can affect the accuracy of LP localization. Thus, coarse detection results obtained in the previous step will be further selected by accumulated vertical edge jump times at the height of 1/3, 1/2, and 2/3 of every Region of Interests (RoI) so as to filter out pseudo candidate LP.

1) Edge detection algorithm

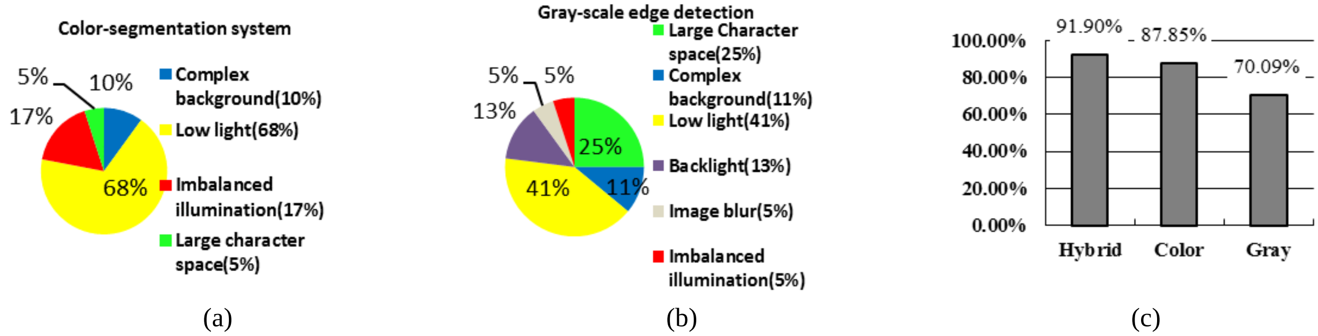


Fig. 5. Reasons for LPR failure for a) the colour-based method; and b) the gray-scale method; and c) the comparison of LP recognition rate of the three systems.

Since in the night time, the accuracy of the colour-based algorithm is more likely to be affected by other light sources. To resolve this problem, the vertical edge detection combined with morphology operation is proposed in Fig. 6. Given that edge information can represent the main structure of the object, the LP text region with rich vertical edges can be obtained by the sobel vertical edge mask on a gray-scale image.

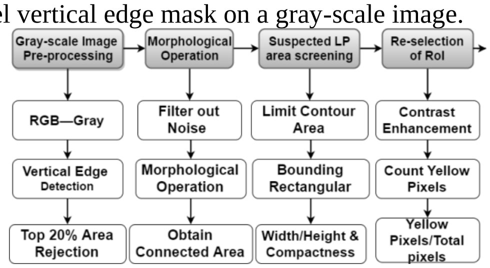


Fig. 6. Gray scale edge detection system.

However, in complicated background, it may contain a lot of dense edge noisy regions. To weaken this issue, we assume that the top 20% areas in the image will not contain any valid LP. Similar to the colour-based algorithm, the morphological operation follows to combine dense vertical edge regions into connect areas and filter out candidate LP by its geometrical features. Finally, with the common feature of dense vertical edges in the coarse detection results, the verification stage helps remove pseudo LP by setting the threshold value of the yellow pixel to improve the detection accuracy.

III. SIMULATION RESULTS AND DISCUSSION

In this section, we present and discuss the simulation results of the proposed LPR algorithm and the semi-realistic simulation of fountain coded data dissemination in VANET.

In the LPR system, the analysed results of the cause of detection failures in the colour-based and gray-scale algorithms are listed in Fig. 5a and 5b. Failure detection caused by low light conditions in the colour-based method received a much higher rate (68%) compared to the gray-scale method (41%). Moreover, the influence caused by imbalanced light in the colour-based method is three times larger than that in the gray-scale method. Summarizing these failure causes, although the recognition rate in the gray-scale method is lower (Fig. 5c), it can make up the flaws of the color-based recognition in the conditions of back-light and uneven light. Therefore, a two-phase approach of LPR is proposed. Color segmentation is the first phase, while the gray-scale edge detection follows if the color-based method fails. In brief, a total number of 321 images are collected under different environmental conditions in Hong Kong. In Fig. 5c, we can see that the hybrid approach gets the best detection accuracy (91.90%) among the three. Besides, we also implemented our LPR algorithm in Raspberry Pi (RPI) in Fig. 7, which can serve as VANET on-board unit for traffic monitoring.

Fig. 7. Implement LPR system in RPI.

In the semi-realistic simulation, we selected the Mong Kok district in Hong Kong, which is one of the busiest districts with a dense and complicated road topology. 23 bus stops and 29 traffic lights are deployed in an area of 274.44×433.39 m^2. Simulation parameters are summarized in Table 2.

TABLE II. THE MONG KOK SCENARIO SIMULATION PARAMETERS.

Scenario Parameters	Traffic Simulator	Scenario Size(m^2)
Values	SUMO+OpenStreetMap	274.44×433.39
Scenario Parameters	Bus Stops	Traffic Light
Values	23	29

As being the communication carrier of the feature detection related multi-media data dissemination, we simulate the inter-bus communication network in NS-3. Given a certain number of buses (60 nodes) in these scenarios, we varied the number of generic vehicles in the network for generating different traffic flow levels (sparse, moderate, congestion) and summarized in Table 3 below.

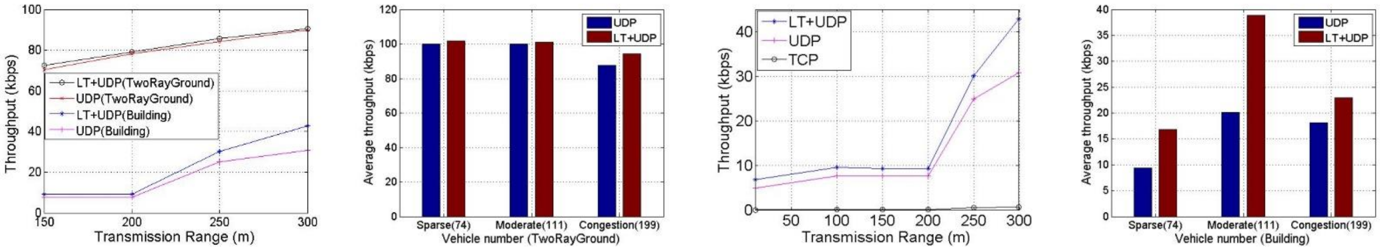
TABLE III. THE MONG KOK SCENARIO SIMULATION PARAMETERS.

Traffic condition	*Vehicle numbers (Bus / Total vehicles)*	*Congestion rate*
Sparse	60/74	-
Moderate	60/111	15%
Congestion	60/199	53%

Therefore, we compared the network connectivity under both two-ray ground and building propagation loss models. With the Greedy Perimeter Stateless Routing (GPSR) routing protocol and 200 m transmission range in Fig. 9, some of the wireless links are disconnected in the building loss model due to the attenuation of buildings.

On one hand, we compared the network performance under both two-ray ground and building propagation loss models in Fig. 8a and 8b. Specifically, under the two-ray ground loss model, the performance of UDP-LT and UDP protocol are very similar and the variation of traffic conditions (sparse, moderate, or congestion) does not affect the network performance much. In fact, this is obviously not sufficient to reflect the realistic conditions of inter-vehicle communications.

On the other hand, with the building propagation loss model



(a) (b) (c) (d)

Fig. 8. Average throughput comparison between UDP-LT, UDP and TCP.

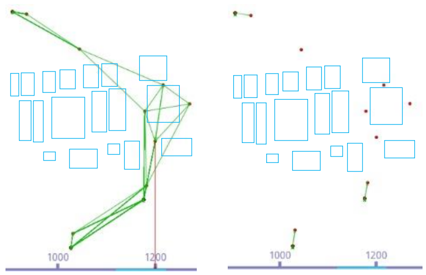


Fig. 9. Network connectivity between two-ray ground (left) and building loss model (right).

and the GPSR routing protocol, we compared our fountain code based data dissemination method with UDP as well as TCP protocols under the same VANET scenario. With a transmission range of 300 m, in Fig. 8c, our UDP-LT protocol can improve the average throughput by more than 28% faster than UDP, and 62 times when compared to TCP. Besides, under various traffic conditions in Fig. 8d with the building loss model considered, the fountain coding method can achieve a more efficient transmission of multi-media data from on-road feature detection. This is because the links get disconnected more easily in our building loss model while the fountain code can combat the packet loss problem in such a lossy network.

Interestingly, we can see from Fig. 8d that the improvement brought upon by UDP-LT is the largest under moderate traffic, and the improvement degrades under congested traffic. This is primarily because over 50% of the bus trips are being delayed under congested condition. For the 30 pairs of inter-bus communication links studied, 30% (i.e., nine node pairs) show poorer throughput performance due to the congestion. When we look into these nine node pairs, we find that the source nodes are not affected by the congestion at all while the destination nodes get delayed by a maximum two minutes, since the simulated congestion mainly happened on the major roads in the district (e.g., Nathan Road). Such disruption leads to poorer connectivity for these nine pairs of nodes and hence degraded performance under the congested scenario.

IV. CONCLUSION

In this paper, we have constructed a framework of LPR and fountain-coded data dissemination through VANET in a semi-realistic inter-bus communication scenario. For LPR, we have evaluated the reasons for detection failures of both the colour-segmentation and gray-scale vertical edge detection approaches. We consequently identified that a hybrid approach with both systems can compensate the detection failure under various illumination conditions. Overall, such approach can achieve a successful LP location rate up to 91.90%, which is more than 20% better than the gray-scale edge detection system alone. We then transplanted our LPR algorithm into the embedded system of RPI to server as a VANET on-board monitoring unit. Equally important, data dissemination with fountain code in the application layer and UDP in the transport layer can achieve more efficient feature detection-related data transmission than generic TCP and UDP under VANET scenarios. Specifically, with the building loss considered, fountain coded data dissemination can achieve a better performance boost than the traditional two-ray ground model under various traffic conditions. This again reminds us that improper modeling of the vehicular traffic and signal propagation in VANET environments could lead to unreliable evaluation results.

All in all, with rigorous verification and optimization of each system module, the feature detection and data dissemination platform can be further utilized to construct inter-vehicle communication networks for both safety-related and infotainment applications. For example, a bus lane monitoring system that vision-enabled buses can extract illegal bus-lane occupying vehicles' LP and transmit such information through VANET to patrol cars for actions. This can significantly reduce the trip time and improve the transportation efficiency of public transport systems.

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