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Applicability of Short Range Wireless Networks in V2I Applications

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Abstract—**It is challenging to meet the reliability and timing requirements of wireless networks used in highly dynamic V2I applications. This paper analyzes the selected wireless networks path loss model in V2I scenarios and defines the applicability indicators, then describes their simulation models and analyses the PHY layer simulation results, and then tests their applicability in V2I scenarios, including the tests configurations and results analysis of PER, communication latency and networks access delay. Finally, the conclusions of selected wireless networks applicability in V2I applications are made.**

I. INTRODUCTION

In order to achieve intelligent management and control of urban transportation, real-time dynamic vehicles to infrastructures (V2I) interactive applications are important parts of the proposed systems [4, 5, 36], which are based on ACP (artificial systems, computational experiments, and parallel execution), with artificial transportation system (ATS) and real transportation system (RTS) parallel execution and interactive processing [1,2,3].

Lots of ITS applications using wireless networks can be the reference of V2I applications: (1) Traffic safety, such as the CitySense traffic data collection and information dissemination project of Harvard University[9], CVIS projects of Cooperative Driving[6,7] ,SAFESPOT [15] etc., (2) Traffic law enforcement, such as University of Maryland TrafficView projects[8], PATH [16], FLEETNET [17,18,19], etc. (3) Traffic control, such as UMass DieselNet smart bus and rail transit of University of Massachusetts[10], etc.; (4) Smart parking applications, such as [23], and others projects [20~22].

The target V2I applications require highly performance of wireless networks, which are probably used in: (1) Vehicles to infrastructures communication, such as bus precise positioning and detection in GPS signal blind areas, midway station or transit hub/terminus, and intersections with bus priority signal support etc. (2) Traffic data acquisition, such as parking lots and bus stations management, vehicle identification and location etc.

The requirements of V2I dedicated wireless networks are descripted as "reliable sensing, low latency communication, multi concurrent assessment, and low power operation". Our earlier survey show that there is not yet a universal solution which can meet all these requirements [24~26]. The feasible way is to deliberately apply different types of wireless networks for different scenarios [11~14]. The traffic environment and communication channel characteristics in those situations should be specially analyzed [12,37~41], which typically include large scale path-loss, multipath and shadow fading, and Doppler Effect etc. [27~29].

The first section of this paper is the introduction of wireless network used in V2I applications. The second section describes the analysis model and testing indicators of wireless networks applicability in V2I applications. The third section includes the simulation models and PHY layer simulation results of selected wireless networks in V2I scenarios. The forth section is about the selected wireless networks applicability testing, including tests configurations and results of PER, communication latency and networks access delay. Finally, the selected wireless networks applicability in V2I applications and future works are concluded.

II. ANALYSIS MODEL AND TESTING INDICATORS OF WIRELESS NETWORK APPLICABILITY IN V2I APPLICATIONS

The analysis model of wireless networks applicability in V2I application include wireless network path loss analysis, wireless networks simulation in typical scenarios, test-beds setting up, V2I communication Testing and deployment verification etc. The path loss analysis is helpful to get deployment recommendation and reduce the somewhat dangerous V2I tests. Wireless network simulation can make the deployment more reliable and detailed. With several types of wireless networks test-beds set up, the Packet Error Rate (PER) and network communication latency are sampled and the Roadside Units (RSUs) and Onboard Units (OBUs) deployment can be verified.

A. Path Loss Model of Wireless Networks in V2I Scenarios

The model used for analysis is that calculates the path loss based upon the transmitter-receiver separation distance and the number and type of obstructions intersecting the straight-line between the transmitter and receiver. The equation for signal path loss (in dB) used in the analysis is given as:

$$P_L(d) = P_L(d_0) + 10n\log_{10}\frac{d}{d_0} + \sum_i O_i \qquad (1)$$

Where $P_L(d_0)$ is equal to the free space path loss with respect to a given reference distance, typically d_0 is set to 1m, n is the path loss exponent, O_i is the number of obstructions of type i that intersect the direct-ray path from the transmitter to the receiver, and E_i is the propagation effect, or amount of

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change in the path loss incurred per intersecting obstruction, for an obstruction of type i.

The analysis models of V2I applications include Line of Sight (LOS) where there are no obstructions between the RSU and OBU and Non Line of Sight (NLOS) where intersections of the direct-ray signal path with building footprints (outlines), foliage boundaries, and other vehicles are included as the propagation affecting variables of the modeled environment. The typical scenario is shown as Fig.1.

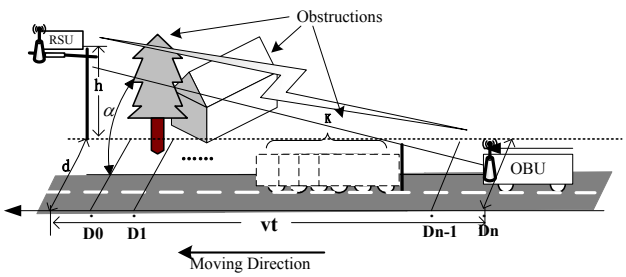


Figure 1. Typical V2I Application Scenario

'D' is the distance between the transmitter and receiver (RSU and OBU), which is divided into sample points sets as $D_i (i = 1, 2, ..., N)$, also represented as vt; 'h' is RSU installation height; 'α' is approximate angel of OBU and RSU, 'd' is vertical distance of RSU to OBU.

The path loss equation (1) can be further expressed when all kinds of power loss are concerned, which is denoted as:

$$P_r = P_t + G_t - L_0 - \Pi_0 - L_t - L_d + G_r \quad (2)$$

Where P_t, G_t, G_r are known as transmitter power, transmitter antenna gain, and receiver antenna gain. L_0 is the free space path loss, denoted as:

$$L_0 = 32.44 + 20\lg f + 20\lg d \quad (3)$$

Where 'f' is the RSU/OBU frequency (in Mhz), 'd' is the distance between RSU/OBU (in km);

Π_0 is fixed power loss and made up of power loss caused by air and dust in traffic environment, by geometric reflections, diffractions and scattering, by connectors, cable and amplifiers equipment used in the construction of the forward link, etc.

L_t is the intersection obstructions power loss, which depends on the different obstruction material.

L_d is the power loss caused by Doppler Effect. The frequency drift is denoted as:

$$\Delta f = f / c * v * \cos\alpha \quad (4)$$

As shown in Fig. 1,

$$\cos\alpha = vt / \sqrt{v^2 t^2 + d^2} \quad (5)$$

And then,

$$\Delta f = (f / c) * (v^2 t / \sqrt{v^2 t^2 + d^2}) \quad (6)$$

When the relative speed of RSU and OBU is low, $2\Delta f$ is small and the modulation power loss is small enough to be neglected. In typical V2I scenarios, Π_0 is almost fixed, therefore, L_0 and L_t are mostly considered and calculated. The received power should be greater than the receiver sensitivity threshold P_{th}, and according to the receiver power estimation:

$$P_t + G_t - (32.44 + 20\lg f + 20\lg d) - \Pi_0 - L_t - L_d + G_r \geq P_{th} \quad (7)$$

The transmission distance can be further estimated as:

$$20\lg d \leq P_t + G_t - (32.44 + 20\lg f) - \Pi_0 - L_t - L_d + G_r - P_{th} \quad (8)$$

B. Testing Indicators of Wireless Networks in V2I Scenarios

Signal Strength Indicator (RSSI), Package Error Rate (PER) and Communication Latency and Network Access Delay are selected as main evaluation indicators of the wireless networks in the analysis model.

1) Signal Strength Indicator (RSSI)

The received signal strength indicator (RSSI) is a measurement and indication of the radio power level being received by the antenna. RSSI can be observed and measured through the use of a dedicated programs or wireless network monitoring tools, such as Wireshark, Kismet or Inssider network monitoring toold for 802.11x WiFi, Chipsets built-in RSSI received Registers Unit for 802.15.4 Zigbee etc. The chipset vendors provide the accuracy, granularity, and range for the actual power (measured as mW or dBm) and their range of RSSI values (from 0 to RSSI_Max), by which the signal strength is measured.

2) PER

The packet error rate (PER) is the number of incorrectly received data packets divided by the total number of received packets. PER is caused by the bit error which is affected by transmission channel noise, interference, distortion, bit synchronization problems, attenuation, wireless multipath fading, etc. In the specific testing process, when the packet is incorrect, it is discarded. Therefore, PER in sampling interval can be denoted as:

$$P = \frac{Receiver_{Rec\_Num}}{Transmitter_{Send\_Num}} \times 100\%$$

3) Communication Latency and Network Access Delay

The defined communication delay is referred to the maximum time spent in transmitting data packets from one node to another, which may differ variously due to the communication channel competition and PER.

OBU sends Req packet to RSU, and wait for receiving the response Ack packet from RSU. If no packet is received, the process is repeated until the handshake is accomplished and the max latency is recorded as Δt. The network access delay can be tested by the similar way. OBU access the network of

RSUs and record the maximum time of successful Req/Ack handshake.

3) Testing Indicators Selection

P_r is represented as RSSI values in the tested platforms. PER is directly influenced by P_r whether it is higher or lower than P_{th}, therefore, PER is considered as the most important and required indicator to the applicability of wireless networks in this paper. At each sample points $D_i\,(i = 1, 2, \ldots, N)$, signal strength (RSSI) and packet error rate (PER) are sampled and the wireless network deployment can be verified.

Tests cases are conducted with various combination parameters sets, including transmit power, data rates, OBU/RSU relative distance and speeds, etc. Based on the PER analysis, then, the communication latency, network access delay tests are carried out.

III. Simulation of Wireless Networks in V2I Applications

Several short range wireless networks are selected for applicability testing, including IEEE 802.15.4/ 802.15.4c Zigbee, which is with low power consumption, low cost, scalable network capacity, simple, stable and reliable MAC layer performance [42,43], and 802.11x WiFi are with physical layer optimization and security specific enhancement, use OFDM technology to support high data rate transmission, provide MAC layer improvements by using CSMA/CA mechanism [44,45].

A. V2I Wireless Networks Simulation Models

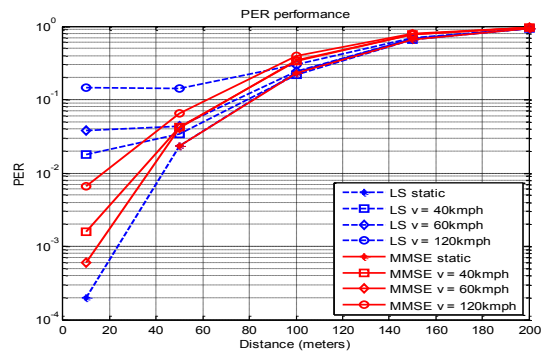
We build a physical layer and MAC layer simulation model of IEEE 802.15.4/802.15.4c ZigBee and IEEE 802.11g protocol based on former referent work[30~35], which settings are shown as Table I. The large-scale fading model of IEEE 802.15.4/802.15.4c ZigBee simulation uses measured path loss model in paper [40], and use small-scale flat fading model. The large-scale fading model of WiFi uses ITU-R M.2135ITU defined Urban Micro (UMi) scenario simulation model, which is classified into LOS and NLOS, and uses the RTV-Expressway channel model measured in real traffic environments as the small-scale fading model [46].

TABLE I. V2I Wireless Network Simulation Model Settings

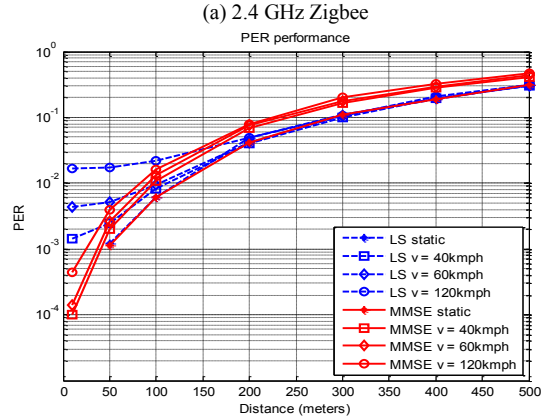
Frequency Band	IEEE802.15.4 2450MHz	IEEE 802.15.4c 780MHz	IEEE802.11g 2.4 GHz
Data Rate	250 kb/s	250 kb/s	12Mbit/s
Modulation	O-QPSK	DSSS + O-QPSK	BPSK/QPSK
Transmit power	10 dBm	10 dBm	10dBm
Payload size	10 bytes	10 bytes	480 bytes
Moving Speeds	0、40、60、120 km/h		
small scale fading model	Rayleigh flat fading; Rician flat fading with K factor 6 dB		
Channel estimation	Use LS (least squares, time-invariant) , MMSE (minimum mean square error, time-varying) to estimate the channels.		
Large scale path loss model	2.4GHz: Urban Micro from ITU-R M.2135 NLOS: PL = 36.7 log10(d) + 22.7 + 26 log10(fc) LOS: PL = 22.0 log10(d) + 28.0 + 20 log10(fc), if 10 m <d<d′BP PL = 40 log10(d) + 7.8 – 18 log10(h′BS) –18 log10(h′UT) + 2 log10(fc), if d′BP <d< 5 000 m (fc is in GHz) d′BP= 4 h′BS h′UT fc/c, is the break point distance (fc is in Hz)		

B. V2I Wireless Networks PHY Layer Simulation Results

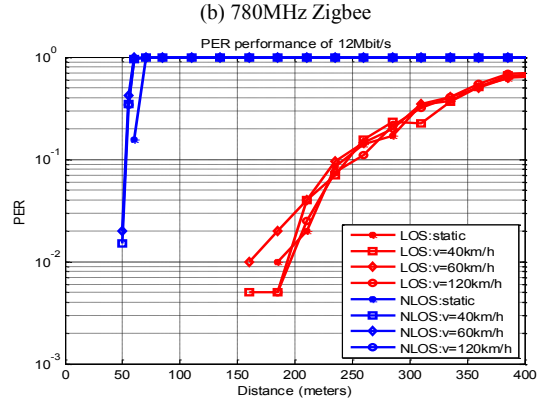
From the PHY layer simulation results, shown as Fig.2, wireless networks PER increase rapidly in NLOS situation, higher frequency is more affected by the path loss fading. In NLOS case, 2.4 GHz WiFi communication distance with PER below 10% is significant decreased to about 70m, 2.4 GHz Zigbee to 100m， and 780MHz Zigbee to 200m. The networks performance degrades while the OBU moves faster because of Doppler Effects, but the influence is still relatively small.



(a) 2.4 GHz Zigbee



(b) 780MHz Zigbee



(c) 2.4 GHz WiFi

Figure 2. PHY Layer PER-Distance Simulation Results (NLOS)

IV. APPLICABILITY TESTING OF WIRELESS NETWORKS IN V2I SCENARIOS

A. Applicability Tests Configurations

In our tests, RSUs are mounted on poles beside the road (5m height for 2.4GHz Zigbee RSU, 3m height for 780MHz Zigbee and 2.4 Ghz WiFi RSU), and OBUs are placed behind the front windshield of testing vehicle. The testing environments include semi-enclosed Ring Road of Universities Town of Guangzhou City, and Proving Ground for Highway and Traffic of the Ministry of Transportation, Beijing City, with low electromagnetic interference and no obvious obstructions in forward link between RSUs and OBUs, which are shown as Fig.3.

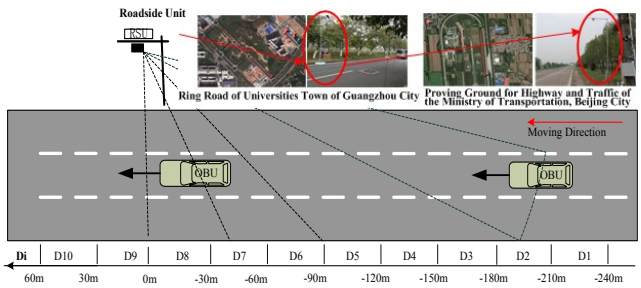


Figure 3. Wireless Network Applicability Testing Deployment

The distance of RSU and OBU is approximately denoted as $D_i\,(i = 1, 2, \ldots, N)$, which is separately presented as negative values, zero and positive values along the OBU moving direction, shown as Fig.3.

The wireless networks nodes are tested in peer-to-peer or networked modes, 2.4GHz Zigbee nodes are programmed with Ti BasicRF test programs and Ti Z-stack protocol stack, 780MHz Zigbee nodes with similar basic peer-to-peer tests programs, and 2.4GHz WiFi nodes with ad-hoc and Ap modes TCP/IP stacks. The platforms profiles are shown as Table II, including Modules and RF Chips, Frequency Band, Modulation Methods, Protocol Standard, etc.

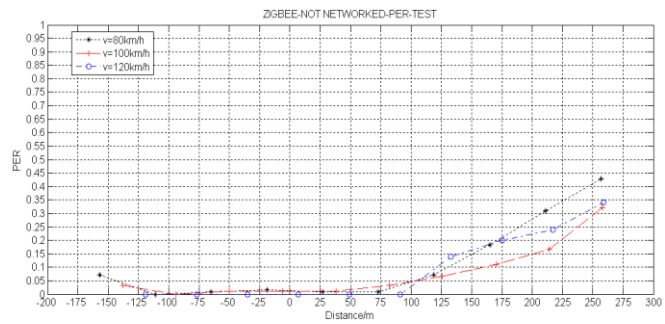
TABLE II. WIRELESS NETWORK TESTBEDS

Protocol Standard	IEEE 802.15.4	IEEE P802.15.4C，IEEE802.15.4-2006	IEEE 802.11 b/g/n
Module	CC2530 Module	HMD30202 Module	EMW3280 Module
RF Chip	CC2530F256+CC 2591	AT86RF212	Marvell 88W8786
Modulation	DSSS（O-QPSK）	BPSK: IEEE802.15.4-2006 O-QPSK: IEEE P802.15.4c,	802.11/802.11b DSSS modulation 802.11g and 802.11n OFDM modulation
Frequency Band	2405MHz~ 2480MHz	China WPAN 779~ 787 MHz	Wi-Fi band 1-13
Transmission Current	<160mA	<250mA	<220mA
Receiving Current	<30mA	<30mA	<30mA
Antenna gain	5db	3db	3db
Transmission Power	22dbm (max), 10dbm (typical)	15dbm (max) 5dbm(typical)	18dbm (802.11b,max) 15dbm (802.11g,max) 10dbm (typical)
Receiving Sensitivity	-97dbm	-110dbm	-91dbm (802.11b) -85dbm (802.11g)
Data Rate	20packet/s (20bytes/ packet)	20packet/s (20bytes/ packet)	20packet/s (20bytes/ packet)

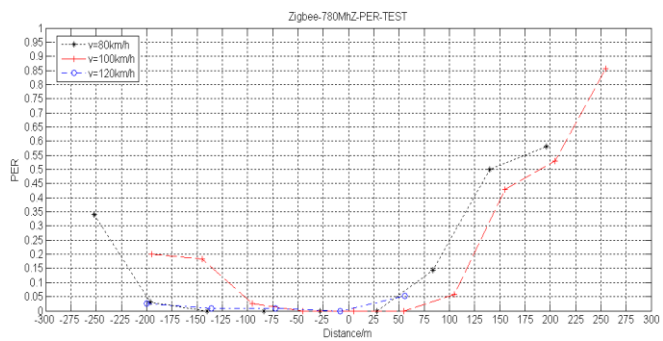
P_t, G_t, and G_r are as Table II shown, L_0 is calculated according to the equation (3). The tests are under good weather and environment without obstructions. Therefore, Π_0 and L_t are small and can be neglected. From the former research, the Doppler Effects caused power loss L_d under speed of 120 km/h is also small and within the toleration of chipsets.

B. V2I Scenarios Wireless Networks PER Tests

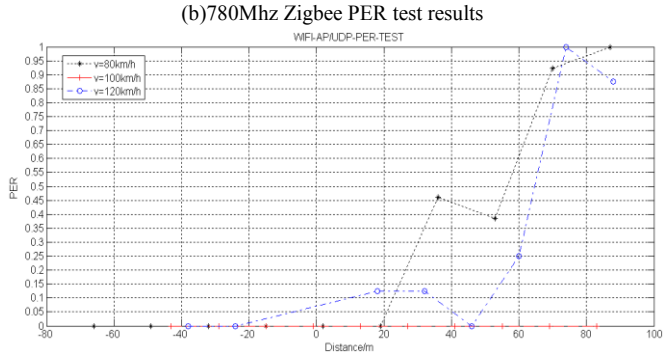
The 2.4Ghz Zigbee, 780MHz Zigbee, 2.4GHz WiFi peer-to-peer PER test results are shown as Fig.4, with vehicle speeds from 60 km/h to 120 km/h and other configurations as Table II.



(a) 2.4Ghz Zigbee PER test results



(b)780Mhz Zigbee PER test results



(c) 2.4GHz WiFi PER test results

Figure 4. Wireless Networks Peer-to-Peer PER Dynamic Tests Results

In real V2I application scenarios, there are always vehicles in front of the OBUs in slow traffic which are looked as obstructions, and power loss, effective communication distance with defined PER should be analyzed.

The V2I scenarios wireless networks PER tests are conducted in parking lots along the roadside, with N stationary vehicles between OBU and RSU, where the effective communication distance decreased and PER rapidly increases. The testing results of 2.4GHz Zigbee and 780 Mhz Zigbee are shown as Table III.

TABLE III. STATIONARY SCENARIOS WIRELESS NETWORK TEST RESULTS OF 2.4GHZ AND 780MHZ ZIGBEE

Vehicles Between OBU/RSU	2.4GHz Zigbee		780MHZ ZIGBEE	
	OBU/RSU Distance(m)	PER (%)	OBU/RSU Distance(m)	PER (%)
1	67	11.45%	67	8.5
2	55	8.39	77	46.7
	62	14.01	55	6.6
3	45	6.40	65	15.4
	55	11.44	6	10.0
4	15	6.40	6	33.7
	21	12.10	67	8.5

C. Wireless Networks Communication Latency and Networks Delay Tests

The 780MHz Zigbee platform dynamic peer-to-peer communication average delay is 3.9ms, while the 2.4GHz Zigbee platform peer-to-peer communication latency and network access delay are shown as Table IV.

TABLE IV. ZIGBEE 2.4GHZ COMMUNICATION LATENCY AND NETWORK ACCESS DELAY TEST RESULTS

Number of Networked Nodes	Networked or not	Latency (ms)
1 Node	NOT Networked	3.7
2 Node	NOT Networked	25
3 Node	NOT Networked	47
1 Node	Networked	1037
2 Node	Networked	1057

The 2.4GHz WiFi network access delay of AP and Ad-Hoc modes of TCP/UDP links are shown as Table V.

TABLE V. 2.4GHZ WIFI NETWORK ACCESS DELAY TEST RESULTS

Wifi Mode	Transfer mode	Network Access Delay (Min ~ Max, in ms)	
AP	TCP	3889	3927
	UDP	3019	3617
AD HOC	TCP	3887	3942
	UDP	2814	2926

D. V2I Scenarios Wireless Networks Applicability Tests Summary

It is a great challenge to meet the reliability and timing requirements of highly dynamic V2I wireless networks applications. From the simulation and testing work, we get some primary summary results of the applicability of them:

(1)The large-scale fading is the important factor of the wireless network effective communication distance, especially with low transmits power. When it is increased (by antenna gain or else), the effective distance becomes longer. The power loss increases and PER raises significantly when there are vehicles in front of the OBUs.

With our platforms configuration, both 780Mhz and 2.4Ghz Zigbee work well within 100m in LOS scenario with PER <= 10% (2.4Ghz Zigbee effective distance is above 200m). But the distance decreases to about 60m when in Vehicles Obstruction NLOS scenario with PER <= 10%. 2.4Ghz WiFi works well with shorter distance about 60m, but with much higher data rate.

(2)The Doppler Effect caused slightly, but limited PER increases when vehicles/OBUs speeds are under 120km/h.

(3)The communication latency of these platforms are small (about 3ms), but the network assessment time are longer (about 3s for WiFi and 1s for Zigbee).

In conclusion, those short range wireless networks can be used in situations with special requirements, but due to the delay and cover ranges, it needs to be further optimized, for example, the RSUs and OBUS should be dedicated deployed, with maximized height and unobstructed communication distance.

V. CONCLUSION

It is challenging to meet the requirements of highly dynamic V2I wireless networks applications. In order to analyze the applicability of selected wireless networks used in V2I applications, this paper analyzes the wireless network path loss model in traffic environment and defines applicability testing indicators. By simulation and testing of selected wireless networks, we get the results of PER, communication latency and networks access delays of them, and get some primary summary results of the applicability, that those selected short range wireless networks can be used in situations with special requirements, but due to the delay and cover ranges limits, they needs to be further optimized and dedicated deployed. There are still lots of future works should be done to make the models more accurate due to the complexities of traffic environments and wireless networks technologies.

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