A Context-Aware MAC Protocol in VANET Based on Bayesian Networks

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***Abstract*—In Vehicular Ad hoc Network (VANET), Carrier Sense Multiple Access (CSMA) mechanism adopted in IEEE 802.11p/WAVE has some drawbacks in latency and delivery ratio when disseminating safety messages periodically. In this paper, a novel context-aware MAC protocol in VANET based on Bayesian Networks (BN) is proposed to improve network performance of high load. BN is introduced to process incomplete, inaccurate and uncertain context information in view of the high dynamic of VANET and vagueness of acquiring context information system. The Contention Window (CW) is adaptively adjusted based on the network communication status inferred from BN. Simulation results demonstrate that compared to IEEE 802.11p/WAVE algorithm, the novel algorithm offers a better delivery ratio and medium access delay.**

***Keywords*—Bayesian; Context-Aware; 802.11p/WAVE**

I. INTRODUCTION

Vehicular Ad hoc Network (VANET) with vehicles being the mobile nodes has received considerable attention from both academia and industry recently. VANET is a special Mobile Ad hoc Network (MANET), and has following characteristics: variable network density, rapid changes in network topology and so on [1]. In VANET, the communication modes, i.e., vehicle to vehicle, vehicle to infrastructure and hybrid communication are expected to be supported [2].

VANET is developed for three class applications, i.e., Safety applications, Convenience (Traffic Management) applications and Commercial applications [3]. In Safety applications, message transmission should have high reliability and low latency, which requires MAC protocol to be efficient and reliable. A vehicle broadcasts beacons periodically, and warning messages to vehicles located in its neighborhood when it is involved in an accident. However, IEEE 802.11p/WAVE protocol cannot guarantee a high reliability and a determined latency, particularly in high-density network. Therefore, it is necessary to design a broadcasting mechanism which can be adaptively adjusted according to the network communication status based on the characteristics of VANET safety messages.

The network environment is very complex for VANET, therefore, it is required to collect enough information to improve network performance. In this paper, a context-aware MAC protocol in VANET is proposed based on Bayesian Networks (BN) [4], which takes into account the information of vehicles, external environment and network performance parameters to reason network communication status and adjust the Contention Window (CW). The major contribution of this work is that BN is adopted to deal with inaccurate context information, and CW size can be adaptively adjusted according to network communication status. Therefore, this technique is effective to improve network performance.

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The rest of paper is organized as follows. In section II, an overview of the state of the art is presented. The proposed scheme is described in section III. Simulation scenarios and results are given in section IV. Finally, we summarize and present future work in section V.

II. RELATED WORK

A. Broadcast mechanism in IEEE 802.11p/WAVE

Broadcast is an important operation in VANET for sharing safety and road information among vehicles [5]. In recent years, there are a lot of literature focusing on broadcast mechanism in IEEE 802.11p/WAVE protocol.

A MAC scheme for broadcast in IEEE 802.11p/WAVE standard during the CCH periods was proposed in [6] to alleviate the performance degradation in control channel. Vehicles start their backoff at a time depending on their geographical position. However, many vehicles are located very close to each other in high-density network, so this scheme cannot decrease collision probability effectively.

A mechanism for dynamic adaptation of transmission power and the CW size for enhancing performance of information dissemination in VANET is presented in [7]. However, the network performance is affected by a lot of factors. Transmission power and the CW size are adjusted based on vehicle density and collision ratio respectively, which is not comprehensive and precise enough.

B. Context awareness

In recent years, there are some researches on MAC mechanism of IEEE 802.11p/WAVE based on context awareness. However, they just gather information of vehicle from sensor, and process the information simply, lacking of further reasoning or prediction.

The channel contention collision of IEEE 802.11p/WAVE protocol for VANETs increases with vehicle density. A context-aware MAC protocol was proposed in [8] for VANET with the basic idea of ensuring only one vehicle access the channel initiatively while others conceal their contending intentions. This scheme uses the hamming competing network to decide which vehicle will access the channel according to

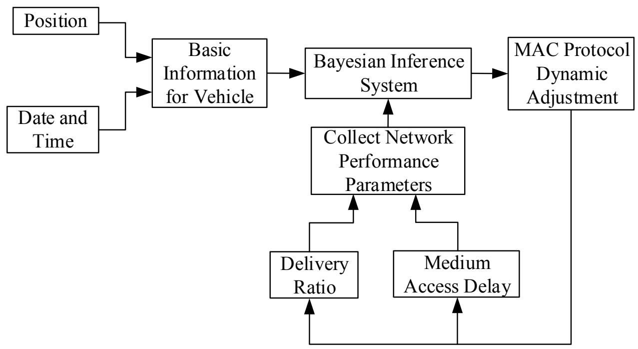

Fig. 1. The context-ware MAC protocol based on BN in VANETs

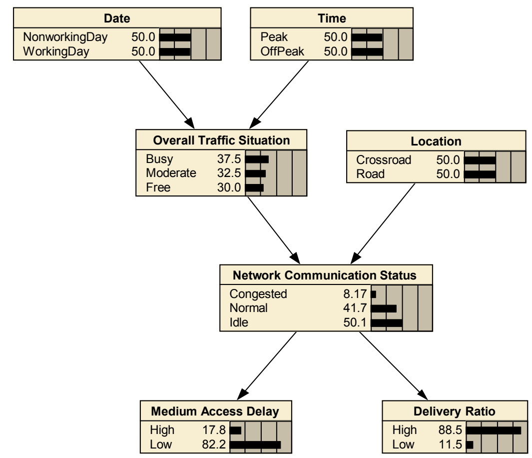

Fig. 2. The BN structure

the context information. In some scenarios, this protocol can reduce delay and improve transmission reliability.

In [9], the authors proposed a distributed beacon scheduling scheme referred to as the context awareness beacon scheduling (CABS) which is based on spatial context information dynamically scheduling the beacon by means of TDMA-like transmission. The proposed CABS scheme shows better performance than the periodic beacon scheduling scheme in terms of packet reception ratio and the channel access delay.

Furthermore, the authors proposed a distributed multi-channel and mobility-aware cluster based MAC (DMMAC) protocol in [10]. In [11], the authors presented a context-aware cross-layer(CACL) broadcast model to reduce contention collision ratio for heavy broadcast traffic. In [12], the authors developed a novel and non-intrusive driver behaviour detection system using a context-aware system in VANET to detect abnormal behaviours exhibited by drivers, and to warn other vehicles on the road so as to prevent accidents from happening.

However, the above literature only focus on the design of system model and collection of information, and a minority of them process the collected information detailedly. Consequently, most of them cannot improve network performance effectively and reliably.

III. Context-Aware MAC Protocol

In this paper, relationship between the MAC algorithm and network performance for Safety application in the urban environment is investgated. Context information includes date, time (i.e. whether is the peak period), vehicle position, delivery ratio and medium access delay.

This paper assumes that all the context information can be collected by context-aware system, and then determines how to use these information to improve the performance of the MAC mechanism in detail. The context-aware MAC protocol is divided into two parts:

a) Reasoning: The current network communication status is reasoned by BN based on context information;

b) Self-adaption: CW size is dynamically adjusted according to the network communication status. The proposed protocol is demonstrated in Fig. 1.

A. Network communication status reasoning mechanism

The main steps of reasoning mechanism include determination of mutual exclusive *hypotheses variables*, determination of mutual exclusive *information variables*, construction of BN diagram and giving a priori probability of each BN node and conditional transition probabilities.

1) Defining BN variables:

a) hypotheses variable: When the vehicle broadcasts safety messages, MAC protocol should be able to adaptively adjust the access parameters according to the network traffic to transmit messages with high reliability and low latency. Therefore, a *hypotheses variable* is defined, denoted as network communication status, to measure whether the network is busy or not. Network communication status has three states, namely, *congested, normal* and *idle*. When the network communication status is in the *congested* state, the collision probability increases, which results in poor network performance. It tends to have low average delivery ratio and high delay with high probability. When the network communication status is in the *idle* state, the network performance is optimal, which is more likely to have high average delivery ratio and low delay. When the network communication status is in the *normal* state, the network performance is normal.

b) Information variables: In this paper, *information variables* include date, time, vehicle location, delivery ratio and medium access delay. The delivery ratio is defined as the ratio between the number of the vehicles receiving the packet successfully and the number of the neighbourhood of the sending vehicles. The Medium Access Delay, MAD, is simply defined as the average total contention delay for a packet at MAC layer before it is successfully transmitted.

2) BN Structure: A BN of n variables is a Directed A-cyclic Graph (DAG) representing the conditional independence between a set of random variables and disposing uncertain information and probabilistic inference upon receiving evidences [4]. Nodes in a DAG represent the random variables and directed arcs between two nodes represent direct causal or influential relations from one variable to the other. Based on the BN variables and the reasoning model has been defined, the structure of BN can be constructed as shown in Fig. 2. In the figure, the overall traffic situation refers to the global vehicle density in a certain area.

We make the following assumptions:

① All vehicles maintain a constant communication range.

② All vehicles have the same transmission time interval and the transmission probability.

Based on the above assumptions, overall traffic situation and location affect network communication status independently.

3) BN Parameters: BN parameters consist of the priori probability, the conditional probability and the information of the BN node. Before setting network parameters, it is necessary to determine the status of each BN node. The status of *hypotheses variable* is shown in Table I, and the status of *information variables* is shown in Table II.

TABLE I
THE STATUS OF HYPOTHESES VARIABLE

Hypotheses variable	State 1	State 2	State 3
Network communication status	Congested	Normal	Idle

TABLE II
THE STATUS OF INFORMATION VARIABLES

Information variables	State 1	State 2	State 3
Date	Non-working day	Working day	
Time	Peak	Off-peak	
Overall traffic situation	Busy	Moderate	Free
Location	Crossroad	Road	
Medium access delay	High	Low	
Delivery ratio	High	Low	

We obtain statistics from some relevant papers [12], [13]. However, not all the required data can be obtained. Yet, some probabilities were still determined based on our experiments. The conditional probability tables are summarized in TABLE V, TABLE III, TABLE IV and TABLE VI.

TABLE III
THE CONDITIONAL PROBABILITY OF MEDIUM ACCESS DELAY

Network communication status	Medium access delay	Probability
Congested	High	0.98
	Low	0.02
Normal	High	0.21
	Low	0.79
Idle	High	0.02
	Low	0.98

TABLE IV
THE CONDITIONAL PROBABILITY OF DELIVERY RATIO

Network communication status	Delivery ratio	Probability
Congested	High	0.02
	Low	0.98
Normal	High	0.94
	Low	0.06
Idle	High	0.98
	Low	0.02

TABLE V
THE CONDITIONAL PROBABILITY OF OVERALL TRAFFIC SITUATION

Date	Time	Overall traffic situation	Probability
Non-working day	Peak	Busy	0.2
		Moderate	0.4
		Free	0.4
	Off-peak	Busy	0.1
		Moderate	0.3
		Free	0.6
Working day	Peak	Busy	0.9
		Moderate	0.1
		Free	0
	Off-peak	Busy	0.3
		Moderate	0.5
		Free	0.2

TABLE VI
THE CONDITIONAL PROBABILITY OF NETWORK COMMUNICATION STATUS (INITIALIZATION)

Overall traffic situation	Location	Network communication status (initialization)		
		Congested	Normal	Idle
Busy	Crossroad	0.13	0.44	0.43
	Road	0.12	0.43	0.45
Moderate	Crossroad	0.08	0.45	0.47
	Road	0.07	0.45	0.48
Free	Crossroad	0.04	0.38	0.58
	Road	0.03	0.34	0.63

The network communication status can be inferred as follows:

$$P_{con} = \frac{p(C|OTS, L) * p(MAD|C) * p(DR|C)}{\sum p(NCS)} \quad (1)$$

$$P_{nor} = \frac{p(N|OTS, L) * p(MAD|N) * p(DR|N)}{\sum p(NCS)} \quad (2)$$

$$P_{idle} = \frac{p(I|OTS, L) * p(MAD|I) * p(DR|I)}{\sum p(NCS)} \quad (3)$$

Where, C, N, I, OTS, MAD, DR, L and NCS represent *congested*, *normal*, *idle*, overall traffic situation, medium access delay, delivery ratio, location and network communication status respectively. P_{con} represents the probability when the network communication status is *congested*, P_{nor} represents the probability when the network communication status is

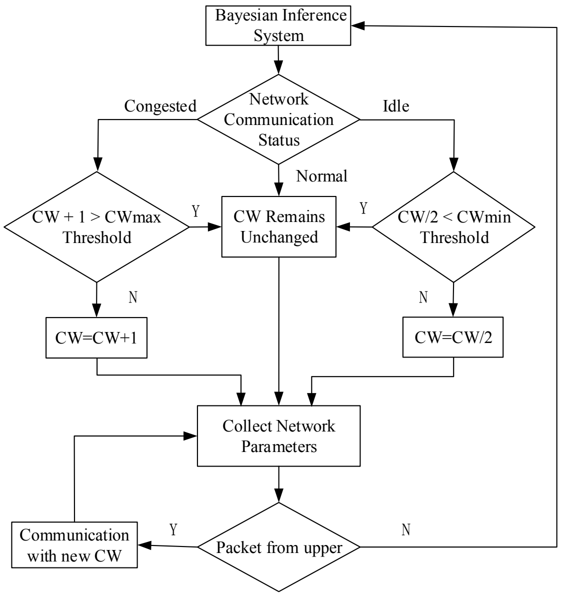

Fig. 3. The dynamic adjustment mechanism of CW

Algorithm 1 An adaptively adjust CW mechanism

if $NCS = congested$ **then**
  if $CW + 1 < CW_{max}\ threshold$ **then**
    $CW \Leftarrow CW + 1$
  else
    $CW unchanged$
  end if
end if
if $NCS = normal$ **then**
  $CW unchanged$
end if
if $NCS = idle$ **then**
  if $CW/2 > CW_{min}\ threshold$ **then**
    $CW \Leftarrow CW/2$
  else
    $CW unchanged$
  end if
end if

normal. P_{idle} represents the probability when the network communication status is *idle*.

The network communication status can be obtained from equation (1), (2) and (3).

$$NCS = \begin{cases} congested \\ (P_{con} = max\{P_{con}, P_{nor}, P_{idle}\}) \\ normal \\ (P_{nor} = max\{P_{con}, P_{nor}, P_{idle}\}) \\ idle \\ (P_{idle} = max\{P_{con}, P_{nor}, P_{idle}\}) \end{cases} \tag{4}$$

As shown in Fig. 2, BN consists of 5 information variables, and each of them have two possible states. It is impossible to detail all 32 possible combinations, so only half of combinations of information variables are shown in Table VII.

TABLE VII
SAMPLES OF THE COMBINATIONS OF INFORMATION VARIABLES

No.	Date	Time	Location	Medium access delay	Delivery ratio	Network communication status	Probability
1	W	P	C	H	H	Normal	0.888
2	W	P	C	H	L	Congested	0.954
3	W	P	C	L	L	Normal	0.656
4	W	P	C	L	H	Idle	0.560
5	W	P	R	H	H	Normal	0.885
6	W	P	R	H	L	Congested	0.952
7	W	P	R	L	L	Normal	0.648
8	W	P	R	L	H	Idle	0.576
9	W	OP	C	H	H	Normal	0.885
10	W	OP	C	H	L	Congested	0.937
11	W	OP	C	L	L	Normal	0.649
12	W	OP	C	L	H	Idle	0.589
13	W	OP	R	H	H	Normal	0.888
14	W	OP	R	H	L	Congested	0.931
15	W	OP	R	L	L	Normal	0.638
16	W	OP	R	L	H	Idle	0.606

Where, W, P, OP, C, R, H and L represent Working day, Peak, Off-Peak, Crossroad, Road, High and Low respectively, which have defined in Table II.

B. Adaptive Broadcast Mechanism

In high-density VANET, using IEEE 802.11p/WAVE protocol, messages are prone to collision, resulting in a very low delivery ratio, and high delay. Vehicles compete for channel through CW. When the collision ratio is very high, it is required to increase CW to reduce the probability of collision. Similarly, when the network load is low, and the CW is too large, it will increase the medium access delay. Therefore, it is required to adjust the CW dynamically according to the network communication status to obtain a better network performance.

Based on this, an adaptive CW adjustment mechanism is proposed combined BN inference system. BN is used to reason the current communication status of the network based on external parameters and network internal parameters. If the reasoning result shows that the network communication status is *congested*, the value of CW will be increased by 1, and it should be smaller than CW_{max} *Threshold*. If the reasoning result shows that the network communication status is *idle*, the value of CW will be divided by 2, and it should be bigger than CW_{min} *Threshold*. CW_{max} *Threshold* is the maximum value of CW, and CW_{min} *Threshold* is minimum value of CW. In simulation, it is assumed that CW_{min} *Threshold* is 3 and CW_{max} *Threshold* is 1023. If the reasoning result shows that the network communication status is *normal*, the value of CW will be unchanged. The process of adjusting is demonstrated by Algorithm 1 and Fig. 3.

TABLE VIII
SIMULATION PARAMETERS

Attributes	Values
Frequency	5.890GHz
Bandwidth	10MHz
Transmit Power	10dBm
Data rate	18Mbps
Packet format	WAVE short message
Modulation	BPSK
Multiplexing	OFDM
Beacon Interval	100ms
Beacon Length	64Bytes
Destination Address	Broadcast
Number of vehicles	60 to 100
Velocities of vehicles	0-70Km/h
Transmission range of vehicles	500m
Simulation time	800seconds

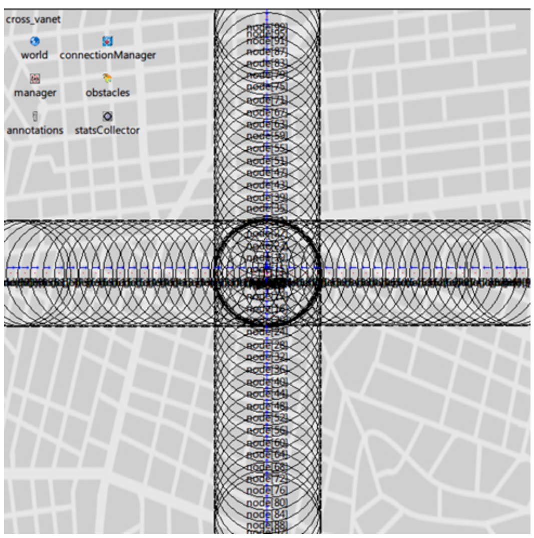

Fig. 4. The simulation scenario

IV. PERFORMANCE EVALUATION

A. Simulation scenarios

In this section, the proposed protocol is validated in OMNeT++-4.2 [14] and SUMO-0.17.1 [15].

Simulations are carried out for a crossroad with a length of 5 km per lane. Vehicle velocity varies from 0 to 70 km/h. All vehicles have the same 802.11p MAC parameters. Vehicles move according to the mobility model from SUMO.

In all the simulations, the simulation time is set to 800s, and the transmission range of each vehicle is 500 m. Vehicles communicate in the V2V mode. Each packet has 64 bytes at a rate of 18Mbps. The number of nodes contending for the channel varies from 60 to 100. The crossroad scenario is described as Fig. 4. Table VIII lists parameters used in the simulation.

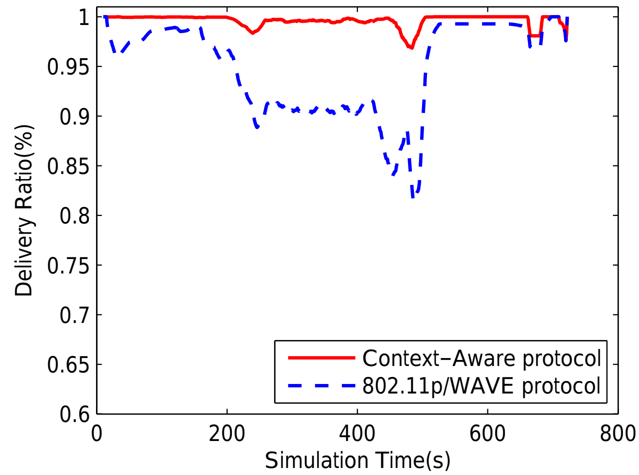

Fig. 5. The comparison of delivery ratio for 60 vehicles overall

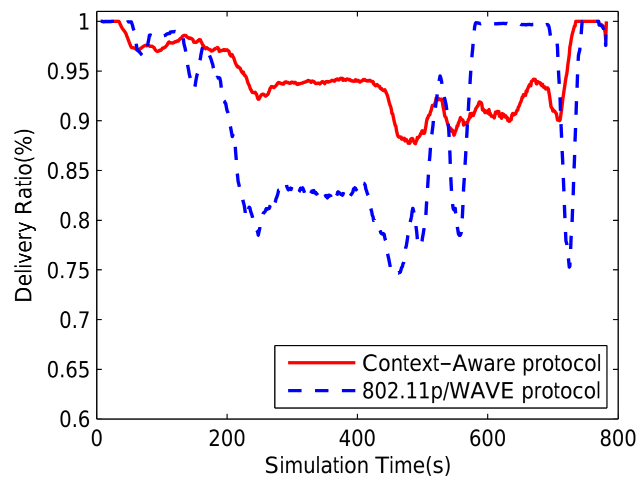

Fig. 6. The comparison of delivery ratio for 100 vehicles overall

It is assumed that all vehicles are synchronized to the control channel interval all the time and the generation time of each status packet is uniformly distributed over that interval with the peroid of 100ms.

In two simulation scenarios, vehicles are generted at the rate of 0.4 vehicles/s and 0.67 vehicles/s through the Flow Function of SUMO respectively during the time from 0 to 150s. Vehicles are congested from 200 to 500s at crossroad.

B. Simulation results

Fig. 5 and Fig. 6 show the delivery ratio of the network when different of MAC mechanism are applied, including the proposed context-aware protocol and IEEE 802.11p/WAVE protocol in two scenarios respectively. It can be seen that the delivery ratio achieved from the proposed protocol is higher than that of IEEE 802.11p/WAVE protocol, especially when vehicles are congested. This is because the CW is adjusted dynamicly according to network communication status, then

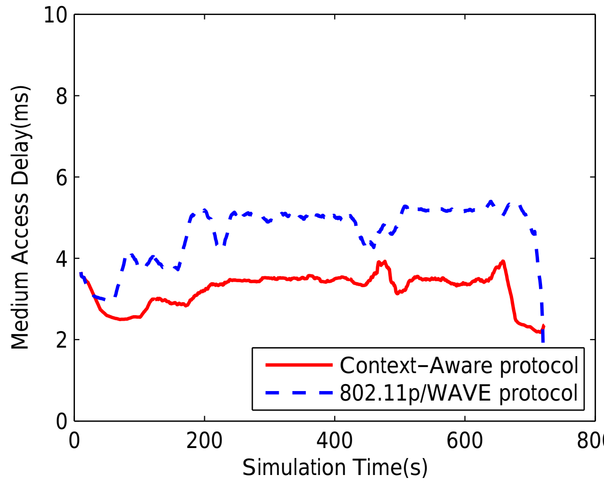

Fig. 7. The comparison of medium access delay for 60 vehicles overall

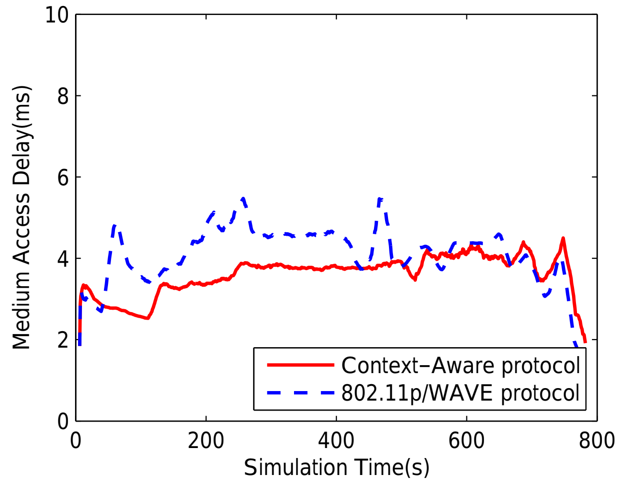

Fig. 8. The comparison of medium access delay for 100 vehicles overall

the collision ratio is decreased correspondingly. When vehicle density is relatively small, the proposed protocol offers a stabler delivery ratio, which can be seen from Fig. 5. In high-density VANET, the proposed protocol also perform very well, compared to IEEE 802.11p/WAVE protocol. In Fig. 6, the delivery ratio of IEEE 802.11p/WAVE is perfect at 580s and decreases at 720s suddenly, while the delivery ratio of the proposed protocol increases smoothly from 580s to 720s. The reason is that vehicles begin leave the crossroad one by one at 560s with high speed, and CW of the proposed protocol is adaptively adjusted, therefore, the delivery ratio of the proposed protocol increases steadily.

Fig. 7 and Fig. 8 plot the medium access delay of the network with different MAC protocol as the simulation time in two scenarios respectively. It can be seen that the medium access delay of proposed protocol is lower than that of IEEE 802.11p/WAVE protocol. Additionally, the medium access delay of the proposed protocol is more smooth and has a smaller delay variation.

V. CONCLUSION AND FUTURE WORK

In this paper, a context-aware MAC protocol in VANET based on BN is proposed. BN is used to reason network communication status, and then the CW is adjusted according to the network communication status dynamically. Simulation results demonstrate that the proposed protocol offers better delivery ratio and medium access delay.

In future work, more factors will be considered to improve the proposed protocol, and the Dynamic Bayesian Network will also be studied to infer network communication status. Furthermore, the proposed mechanism will be applied to V2I scenario.

REFERENCES

[1] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, and H. Zedan, "A comprehensive survey on vehicular ad hoc network," Journal of Network and Computer Applications, vol. 37, pp. 380-392, Jan. 2014.

[2] M. Sichitiu and M. Kihl, "Inter-vehicle communication systems: a survey," Communications Surveys Tutorials, IEEE, vol. 10, no. 2, pp. 88-105, Feb. 2008.

[3] F. Bai, H. Krishnan, V. Sadekar, G. Holland, and T. ElBatt, "Towards characterizing and classifying communication-based automotive applications from a wireless networking perspective," in PROCEEDINGS OF IEEE WORKSHOP ON AUTOMOTIVE NETWORKING AND APPLICATIONS (AUTONET), 2006.

[4] D. Heckerman, D. Geiger, and D. Chickering, "Learning bayesian networks: The combination of knowledge and statistical data," Machine Learning, vol. 20, no. 3, pp. 197-243, Mar. 1995.

[5] A. Rahim, I. Ahmad, Z. S. Khan, M. Sher, M. Shoaib, A. Javed,R. Mahmood, and V. Ad, "A comparative study of mobile and vehicular adhoc networks," Nov. 2009.

[6] A. Ahmad, M. Doughan, I. Mougharbel, and M. Marot, "A new adapted back-off scheme for broadcasting on ieee 1609.4 control channel in vanet," pp. 9-15, June. 2012.

[7] D. Rawat, D. Popescu, G. Yan, and S. Olariu, "Enhancing vanet performance by joint adaptation of transmission power and contention window size," Parallel and Distributed Systems, IEEE Trans, vol. 22, no. 9, pp. 1528-1535, Sept. 2011.

[8] Q. Xu, H. Fan, S. Guo, and X. Xiao, "A context-aware mac protocol for vanets," in Wireless Algorithms, Systems, and Applications, vol. 7992, pp. 135-150, 2013.

[9] S. Bai, J. Oh, and J. il Jung, "Context awareness beacon scheduling scheme for congestion control in vehicle to vehicle safety communication," Ad Hoc Networks, vol. 11, no. 7, pp. 2049-2058, Sep. 2013.

[10] K. Hafeez, L. Zhao, J. Mark, X. Shen, and Z. Niu, "Distributed multichannel and mobility-aware cluster-based mac protocol for vehicular ad hoc networks," IEEE Trans. Veh. Technol., vol. 62, no. 8, pp. 3886-3902, Oct. 2013.

[11] A. Ouksel and D. Lundquist, "A context-aware cross-layer broadcast model for ad hoc networks," Procedia Computer Science, vol. 10, pp. 517-524, Apr. 2012.

[12] S. Al-Sultan, A. Al-Bayatti, and H. Zedan, "Context-aware driver behavior detection system in intelligent transportation systems," IEEE Trans. Veh. Technol., vol. 62, no. 9, pp. 4264-4275, Nov. 2013.

[13] JingGuo, "Floating car databased measures and approach to the assessment of road traffic operations for beijing," Ph.D. dissertation, BeiJing:BeiJing JiaoTong University, Dec. 2006.

[14] "Omnet++," [Online]. Available: http://www.omnetpp.org/

[15] "Sumo simulation of urban mobility," [Online]. Available: http://sumosim.org/