Cross – Layer Safety – Critical Broadcast Service Architecture Integrating VANETs with 3G Networks in IoT Environments

Zhang Lin, Liu Yu, Wang Zi, Du Yingtian
Key Laboratory of Universal Wireless Communications, Ministry of Education, Beijing University of Posts and Telecommunications, Beijing 100876, P. R. China

Abstract: As Vehicle Ad Hoc Networks (VANETs) is part of the applications of the Internet of Things (IoT), and Vehicles in VANETs periodically broadcast the beacon message for status advertisement to provide public safety, the impacts of the network parameters on the reliability of broadcast messages are investigated and discussed; meanwhile, a cross-layer safety-critical broadcast service architecture is proposed to obtain an optimized set of packet loss rate and delay based on the Neural Networks (NN) and Back Propagation (BP) algorithm to dynamically adjust the transmission rate-power pairs. Simulation results illustrate that the proposed mechanism can effectively improve the reliability performance while maintaining the fairness among vehicles.

Key words: Internet of Things (IoTs); VANETs; safety-critical broadcast service; reliability analysis

I. INTRODUCTION

1.1 Background

The IoTs arena as of today resembles the "Wild West" of a couple of centuries ago. The IoTs vision [1] of pervasively connecting smart things will provide a unique chance to enable a rich set of evolutionary as well as revolutionary applications and services. With the increasing popularity of vehicles and the rapid development of wireless communication technologies, how to ensure driving safety has been gaining more and more attentions in VANETs as a part of the IoTs applications. Vehicles in VANETs sense, log, interpret what's occurring within themselves and the world, act on their own, intercommunicate with each other, and exchange information with people. The wireless networks in the vehicular environment can be categorized as a kind of mobile sensor network designed to enable communications either between on Board Unit (OBU) and Road Side Equipment (RSU) or among OBUs. Vehicles employ IEEE 802.11p/1609.x protocols [2-3] or 3G cellular networks to communicate with other OBUs or RSUs in the vicinity. By sharing current traffic information among OBUs and RSUs, vehicles can learn about the traffic accidents or congestions promptly. Furthermore, intelligent decisions are made to assist the drivers to avoid the traffic accidents and the traffic jams in metropolitan roads.

The primary goal of IEEE 802.11p/1609.x protocol families is to provide a robust wireless access adapting to vehicular environments in which channel conditions and network topologies vary from time to time. An overview of the protocol families is illustrated in Figure 1. Till the paper writing time, the IEEE 1609.x families consist of seven protocols: 1609.0 ~ 1609.5 and 1609.11, in which the architecture and the key components of Wireless Access in Vehicular Environment (WAVE) system are specified. In WAVE, traditional TCP/UDP/IP protocol suite and the new WAVE mode Short Message Protocol (WSMP) are both supported. On the other hand, the D10.0 version of the IEEE P802.11p [2] follows 802.11a's OFDM standards operating at 5.9 GHz in the PHY layer and IEEE 802.11e's EDCA channel access strategy in the MAC layer. Besides, IEEE 802.11p defines a new scenario dedicated for vehicle communication where complex authentication and association procedures are omitted. Cellular networks' capabilities, especially that of the Third-Generation (3G) and next-generation, translate into great potential in the vehicular environment, far beyond the provision of data connectivity [4]. Besides providing backup communications for vehicles, it has been demonstrated that the 3G mobile network infrastructure is capable of ensuring timely message dissemination throughout large areas. The use of heterogeneous access technologies in vehicular environments would enable new and richer communication opportunities. The main innovation in this article is the use of 3G networks to gather relevant control information in the OBU-to-RSU direction.

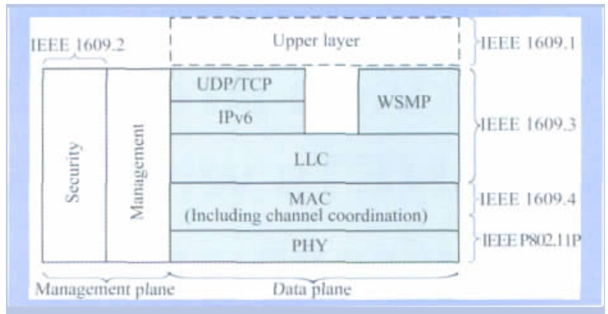

Fig.1 Overview of the IEEE 802.11p/1609.x protocol families

In the safety-critical broadcast service, periodic beacons are generated periodically to announce the vehicles' status (e.g. current position, moving speed and direction). Many previous studies [5-11] assumed that these beacons could be received timely and without any loss or error. However, the simulation results in Ref. [12] revealed that not only many beacon will be lost when the vehicle density is high, but also the fairness deterioration problem of the beacon dissemination among vehicles came out. Reducing the network load offered by one-hop broadcast communications is a critical issue in vehicular communications due to the trade-off between required bandwidth and accuracy of cooperative awareness. Although high beacon transmission rate in the application layer, which is necessary for a subject vehicle to distribute its status information to other vehicles in its vicinity timely, it may lead to performance degradation due to channel congestion on the contention-based IEEE 802.11p MAC layer. Furthermore, high beacon transmission power in the physical layer, which enlarges the transmission range and thus enables the subject vehicle to broadcast its status to faraway cars, may also result in channel congestion as the limited channel resource is shared by more cars. Hence, the question that how often and how far these periodic beacons can be broadcasted should be studied carefully. Besides, fairness should also be considered, since even only one vehicle enduring severe performance deterioration will cause serious influence under complex traffic situation.

1.2 Related work

To fight against road transport problems, the intelligent car initiative project and the vehicle infrastructure integration project [13] were proposed by the European Commission by the United States. These research and development projects have created a solid technical foundation for vehicular communications, and have also provided some preliminary experiments.

For vehicular environments, Ref. [5] presented a distributed and fair power adjustment scheme to control the load of the periodic message dissemination and the emergency message dissemination within a geographical area. Recent study [6] proposed to tune the beacon frequency according to the current traffic situation. Therefore, the required beacon delivery rate can be maintained. Authors in Ref. [7] analyzed the behavior in a Rayleigh fading channel, and provided power control and congestion control strategies to maximize broadcast efficiency. But Refs. [5-7] only took one factor into consideration, either the beacon transmission power or the beacon sending rate. In Ref. [8], the author analyzed the effect of different choices of rate and range then presented models that quantify the network performance in terms of its ability to disseminate tracking information. A joint rate-power control algorithm was put forward in Ref. [10] to adjust the beacon transmission rate and power based on the dynamics of the vehicular network and the safety-driven tracking process. But Ref. [9] focused on the accuracy of safety applications in the upper layer rather than on the network performance from the perspective of Quality of Service (QoS) metrics. Illuminated by the previous works, we aim to dynamically optimize both the beacon transmission rate and power simultaneously, in terms of QoS metrics such as packet loss rate and delay.

In VANETs, the performance requirements such as the packet loss rate, the delay, the fairness among vehicles, etc. must be guaranteed simultaneously to achieve safe driving. NN is an effective tool to realize multi-input multi-objective optimization. Refs. [11-12] have already applied NN to adjust the network parameters in wireless local area networks. Based on this thought, we propose the cross-layer safety-critical broadcast service architecture integrating VANET with 3G networks to adjust the beacon transmission rate and power using a BP algorithm based on NN.

1.3 Contributions

Our main contributions in this paper are described as follows. First, we introduce a BP algorithm based on NN into the VANETs field to achieve multi-objective optimization; Second, according to the current traffic situation, a cross-layer safety-critical broadcast service architecture integrating VANET with 3G networks is presented to adjust the beacon transmission rate and power dynamically in terms of packet loss rate and delay; Third, the proposed architecture could maintain the fairness among vehicles while balancing the network load and the accuracy of active safety applications; Finally, we provide the performance comparison at different traffic densities through extensive simulations.

The remainder of this paper is organized as follows: Section II presents our proposed cross-layer safety-critical broadcast service architecture. The core algorithm of BP based on NN in the proposed architecture is described in Section III. In Section IV, we construct the simulation scenarios to evaluate the effectiveness of the proposed scheme. Section V draws the conclusion.

II. CROSS-LAYER SAFETY-CRITICAL BROADCAST SERVICE ARCHITECTURE

2.1 Overview

The performance metrics of vehicular networks such as delay and packet loss rate are affected by the beacon transmission rate and power. To increase the reliability of the beacon transmissions, we usually raise the beacon transmission rate in the application layer or the beacon transmission power in the physical layer. However, both high beacon transmission rate and power will aggravate channel congestion for the limited channel resources. So the beacon transmission rate and power should be determined carefully based on the network situation and the communication requirements. We assume that each vehicle is equipped with sensors, GPS devices and a digital map, and it is always in the coverage of 3G communication networks. In metropolitan scenarios, the vehicles' speeds are relatively low. So the resident time of vehicles in one RSU's coverage is long enough to carry out the proposed architecture.

2.2 Concept of administration region

We introduce the concept of Administration Region (AR) to identify the region within which the beacon broadcasting of vehicles is controlled by the specific RSU. Note that one AR is larger than the power coverage of the RSU and there is only one RSU in an AR (denoted as serving RSU).

Vehicles equipped with GPS devices can sense which AR it belongs to by comparing the distances between itself and RSUs with certain distance threshold. The RSU whose distance to the vehicle is shorter than the threshold can be the serving RSU. The vehicle is controlled by the serving RSU and obeys the instructions of this RSU during its residence time. That is to say, this vehicle belongs to the corresponding AR.

Vehicles which are out of the power scope can communicate with RSUs by multi-hop routing. As illustrated in Figure 2, the right circle means the power coverage of RSU2, while the rectangle means the AR of RSU2. Vehicle A is in the AR of RSU 2, but it's not within RSU2's power range. Vehicle C within the power scope of RSU2 receives messages from RSU2 and relays them to other vehicles in the same AR. The multi-hop path of these messages to vehicle A is RSU2-C-D-B-A.

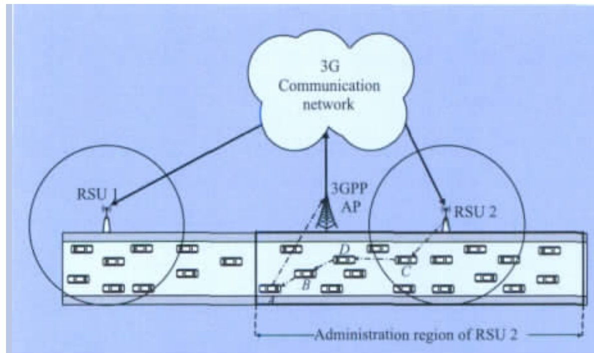

Fig.2 Architecture of cross-layer safety-critical broadcast service architecture

2.3 Functional description

In proposed cross-layer safety-critical broadcast service architecture, OBUs are in charge of sensing their own driving behaviors (e.g. speed, position, acceleration and so on) using equipped sensors and reporting them to the serving RSU and nearby OBUs. Furthermore, OBUs are responsible for reporting their beacon records to the serving RSU. Based on the information submitted by OBUs, the RSU will analyze the network performance metrics (e.g. delay, packet loss rate), execute the BP algorithm based on neural network (illustrated in Section III) to calculate a set of guide beacon rate-power pairs, and distribute those values to every vehicle in its AR.

2.3.1 OBU

For information collection, each vehicle contains a database, which stores the history sending-receiving records. The history records can be divided into two categories: the sending record and the receiving record. The former contains the current position of the vehicle, beacon sequence number (No.), sending time (T_T time), transmission rate (the interval between two consecutive beacons' broadcasting) and the power of transmission, as shown in Table I, which takes vehicle A as an example. Whereas the receiving record contains the current position of the vehicle, beacon sequence No., receiving time (T_R time), and the sender ID of the received beacon, as shown in Table II, which takes vehicle C as an example.

Table I Format of beacon sending records (vehicle A in Fig.2)

No.	T_T time/ (hh:mm:ss:ms)	Position	Beacon rate/ ms	Beacon power /dBm
11 134	10:15:34:935	(23.1, 56.5)	103	28.8
11 135	10:15:35:038	(22.4, 58.6)	103	28.8
11 136	10:15:35:136	(20.3, 59.5)	98	26.3
11 137	10:15:35:234	(19.6, 60.4)	98	26.3

Table II Format of beacon receiving records (vehicle C in Fig.2)

No.	Sender ID	T_R time/ (hh:mm:ss:ms)	Position
11 134	A	10:15:35:089	(13.1, 44.5)
11 134	B	10:15:35:093	(13.1, 44.5)
11 135	B	10:15:35:099	(13.2, 44.6)
11 137	A	10:15:35:457	(13.2, 45.6)

The database should be updated once the vehicle broadcasts or receives a beacon. For memory efficiency, the history records should be deleted when its lifespan is expired (e.g. 30 s). These history records should be submitted by the vehicle to its serving RSU periodically.

For the transmission of these beacon records, although IEEE 802.11p has the ability to conduct multi-hop routing to transmit data from distant OBUS to the RSU, the stability and timeliness can not be guaranteed because of the dynamic network topology and limited channel resources. So the stable and high-speed 3G communication network instead of IEEE 802.11p is chosen as the data uplink path, to ensure the integrity and accuracy. Vehicles can send their beacon history records through 3G interfaces periodically in order to update the beacon history records in its serving RSU. Figure 2 illustrates the typical scenario of the proposed architecture.

2.3.2 RSU

There is also a database located in the RSU, which stores the records of each beacon broadcasting in its AR, as shown in Table III. The "No." means the sequence number of the broadcasted beacon from the sender. The "sender ID" and "receiver ID" can be determined by the international mobile subscriber identification number.

According to the "T_R time" and "T_T time" field, the beacon transmission latency between two vehicles can be calculated. Furthermore, the packet loss rate between two vehicles during one period of time can also be obtained with the help of the sender ID and receiver ID.

The calculating of these performance metrics should be conducted frequently enough. Once the performance deterioration exceeds the required threshold (e.g. the packet loss rate is above 15%), the learning phase and the decision phase will be initiated. In the learning phase, NN can accurately model the mapping between QoS (i.e. delay, packet loss rate) and the beacon rate-power. In the decision phase, BP algorithm is conducted to optimize the beacon rate-power for given QoS metrics.

As Figure 3 illustrates, the RSU encapsulates the ID number of the vehicle, as well as the corresponding guide beacon Rate-Power values (R-P in Figure 3) into two consecutive fields of the data segment. In such way, the RSU downlink broadcasts the frame containing new beacon rate-power pairs to all the vehicles in its AR based on IEEE 802.11p. Vehicles within the RSU power coverage

Table III Format of aggregated beacon records

No.	Sender ID	T_T time /(hh:mm:ss:ms)	Position (sender)	Receiver ID	T_R time /(hh:mm:ss:ms)	Position (receiver)
11 134	A	10:15:34:935	(23.1, 56.5)	C	10:15:35:089	(13.1, 44.5)
11 134	B	10:15:34:955	(17.1, 44.5)	C	10:15:35:093	(13.1, 44.5)
11 134	B	10:15:34:955	(17.2, 44.6)	A	10:15:35:094	(23.2, 56.7)
11 135	B	10:15:35:047	(17.2, 44.6)	C	10:15:35:099	(13.1, 44.6)
11 137	A	10:15:35:234	(19.6, 60.4)	C	10:15:35:457	(13.2, 45.6)

should forward this frame to other vehicles by multi-hop routing in the same AR. Finally, every vehicle in the AR configures its own beacon rate and power according to the received frame.

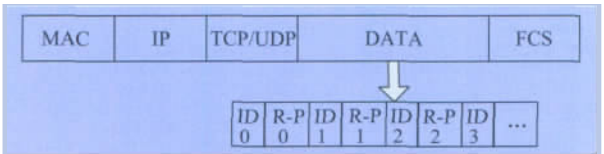

Fig.3 IEEE 802.11p downlink MAC frame structure

The detailed decision procedure of the proposed architecture on RSU is shown in Figure 4.

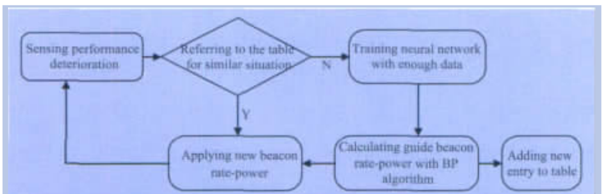

Fig.4 The detailed decision procedure of proposed architecture on RSU

III. BACK PROPAGATION ALGORITHM BASED ON NEURAL NETWORK

In the proposed cross-layer safety-critical broadcast service architecture, the BP algorithm based on the NN is proposed to compute and adjust the optimal beacon rate and power according to the network conditions. In this section, we describe the BP algorithm based on neural network in details. The BP algorithm consists of two phase: neural network training and BP based beacon rate-power adjusting.

3.1 Neural network training phase

As mentioned above, the performance metrics of WAVE network (such as delay, packet loss rate and etc.) are affected by the beacon transmission rate and the transmission power of each vehicle. For low beacon transmission rate, some important safety messages cannot be received timely to inform the instant road condition; for high beacon transmission rate, the beacon may be discarded due to network congestion. For low transmission power, the coverage is limited and the multi-hop routing is adopted; for high transmission power, the interference can degrade the communication quality. So the transmission rate and power should be carefully adjusted to achieve the optimal performance. NN is an effective tool to realize the multi-input multi-objective optimization.

Consider M vehicles with transmitting heart-beat beacons for safe message delivery. Since the QoS metrics, such as the packet loss rate and the delay are affected by the beacon transmission rates and the powers of all vehicles, let β_i denotes the ith ($i = 1, 2, \cdots, M$) vehicle's beacon transmission rate or power, we can denote the correlation function $f(\cdot)$ between the QoS requirements and the transmission rates or powers as following:

$$(QoS_1, QoS_2, \cdots, QoS_K) = f(\beta_1, \beta_2, \cdots, \beta_M) \quad (1)$$

Note that, we only choose K QoS metrics to represent the performance of the whole vehicular network.

In order to evaluate the fairness of the WAVE network, we define the cost-reward function as following:

$$C = \sum_{i=1}^{K} \frac{(QoS_i - QoS\_THR_i)^2}{QoS\_THR_i} \quad (2)$$

where QoS_THR_i is the QoS requirement of the ith vehicle. In other words, we call QoS_THR_i as the optimization goal. Clearly, the wireless medium is fairly shared according to the QoS requirement if the cost-reward function C is minimized. Thus, the goal of our optimization is to find a set of proper beacon transmission rate-power pairs to minimize C.

The nonlinear correlation function $f(\cdot)$ can be obtained with the Multi-Layer Perception (MLP) neural network (shown in Figure 5). With a large amount of training data which take the beacon transmission rate-power as input and the QoS metrics as output, the NN can be established. We employ a three-layer MLP here. The number of neurons in the input layer equals to twice the number of vehicles M. There are 4M neurons in the hidden layer. In the output layer, the number of neurons equals to K. We denote it as a 2M-4M-K MLP.

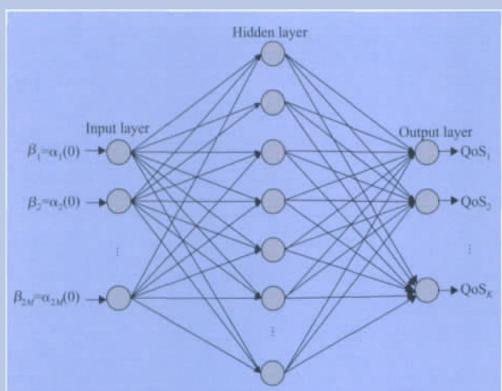

Fig.5 Architecture of neural network

In the 2M-4M-K MLP NN, $a_i(l)$, the output of the ith neuron at the lth layer can be described as following:

$$u_i(l) = \sum_{j=1}^{N_{l-1}} \omega_{ij}(l)a_j(l-1) + \theta_i(l) \tag{3}$$

$$a_i(l) = h\left[u_i(l)\right];\ 1 \leqslant i \leqslant N_l,\ l = 1, 2 \tag{4}$$

where N_l is the number of neurons at the lth layer (i.e. $N_0 = 2M$, $N_1 = 4M$, $N_2 = K$), $u_i(l)$ is the activation function, and $\omega_{ij}(l)$ is the weighted factor connecting the output of the jth neuron at the (l-1)th layer to the activation of the ith neuron at the lth layer; $\theta_i(l)$ is the bias. The transfer function h(•) is the sigmoid function at the hidden layer and linear function at the output layer:

$$h\left[u_i(l)\right] = \begin{cases} u_i(l) & l = 2 \\ \dfrac{e^{u_i(l)} - e^{u_i(l)}}{e^{u_i(l)} + e^{u_i(l)}} & l = 1 \end{cases} \tag{5}$$

From Eqs. (3) and (4), we can say that the neural network has been trained only when the weights of the neural network are determined.

As mentioned above, enough data samples for training are indispensable when building the nonlinear correlation function f(•) with neural network. So that the Mean Square Error (MSE) between the training data and the output of the neural network can be very small, which means the trained neural network can reflect the correlation well. Due to the limited computation time constrained by the real-world implementation, we suggest that the initial weights of the neural network should be obtained roughly through offline training. Based on these coarse weights, a few of precise modifications can be made later in real vehicular scenarios (online training).

3.2 BP based beacon rate-power adjusting phase

In BP based beacon rate-power adjusting phase, BP algorithm is conducted to optimize the beacon rate-power for given QoS metrics. Let β_i^n denote the ith (i = 1, 2, …, M) vehicle's beacon transmission rate or power of the nth iteration, and β_i^n is also the input of the neural network (i.e. $\beta_i^n = a_i^n(0)$). The gradient learning formulas to minimize C are as following:

$$\beta_i^{n+1} = \beta_i^n + \mu\lambda_i^n(0);\quad i = 1, 2, \cdots, M \tag{6}$$

where $\lambda_i^n(l) = -\partial C/\partial a_i^n(l)$ and μ is the adjusting rate.

To compute the minus gradient of C for minimizing C with respect to $a_i^n(0)$, $\lambda_i^n(0)$ should be calculated according to the following equation:

$$\lambda_i^n(l) = \sum_{j=1}^{N_{l+1}} \lambda_j^n(l+1)\, h'\left[u_j(l+1)\right]\omega_{ji}(l+1) \tag{7}$$

Eq. (7) means that the $\lambda_i^n(l)$ of the lth layer is determined by the $\lambda_i^n(l+1)$ of the (l+1)th layer. Note that, $\omega_{ji}(l+1)$ means the weight connecting the output of the ith neuron at the lth layer to the activation of the jth neuron at the (l+1)th layer. h′【】 is the derivate of the transfer function.

For the trained neural network consisted of three layers, $\lambda_i^{(n)}(2)$ can be first derived from the cost-reward function. So $\lambda_i^{(n)}(1)$ and $\lambda_i^{(n)}(0)$ can be successively derived with Eq. (7).

After the phase of NN training and the phase of BP adjusting, the guide beacon rate-power values can be obtained to configure the network parameters according to the real-time network situation and QoS metrics.

IV. PERFORMANCE EVALUATION AND ANALYSIS

To verify the effectiveness of the proposed architecture, we first simulate a specific scenario to test the packet loss rate and the delay performance compared with the original mechanism defined in IEEE 802.11p. Then we simulate several road scenarios and different vehicle densities to give the optimal beacon transmission rate-power values and further verify our proposed architecture. We conduct our simulations via NCTUns 6.0 network simulation tool [14]. NCTUns running on Linux Fedora is an open source integrated simulation platform, which is now widely used in wireless vehicular communications network researches. With the GUI in it, users can easily construct the desired road network, and manage the mobility of cars. Furthermore, NCTUns can generate the realistic simulation data of TCP/UDP/IP protocol stack, which will be of great significance for data analysis.

4.1 Performance evaluation and comparison

Firstly, we design a scenario, shown in Figure 6, to verify the effectiveness of the proposed architecture. The number of lanes per road is set to 2, the width of each lane is 5 m, and there are 8 intersections in this scenario. Initially, 20 vehicles are randomly placed on the road. The simulation time is 200 s.

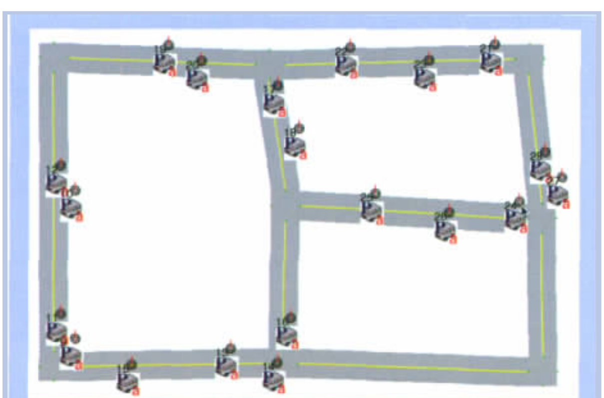

Fig.6 Scenario with 20 vehicles

Then, we compare the original mechanism and our proposed architecture in terms of the average delay and average packet loss rate of the vehicular network. In order to adapt to the real-time network conditions, the proposed architecture is carried out on RSU every 10 s to produce the guide rate-power pairs for each vehicle. The rate and power values after each calculation are shown in Figures 7 and 8, where the dotted lines mean the fixed values defined in the original IEEE 802.11p and the solid lines mean the guide rate-power generated by our proposed architecture. Figures 9 and 10 show the average delay and the average packet loss rate of the beacons as the function of the simulation time respectively. Our mechanism initiates at 30 s.

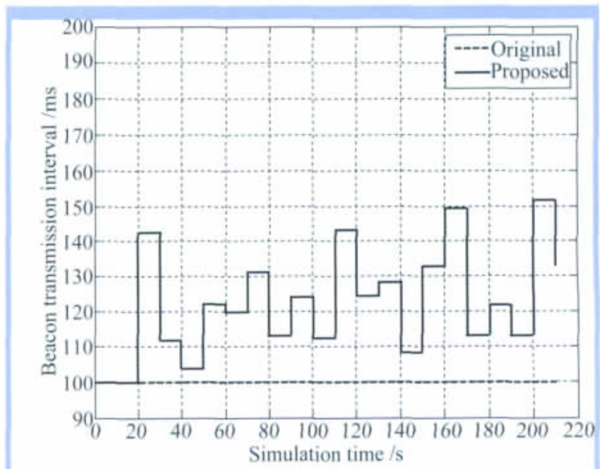

Fig.7 Comparison of beacon transmission rate

As illustrated in Figures 7, 9 and 10, the calculated values of the beacon transmission rate are always higher than the original values. So the transmission interval is enlarged to decrease the number of beacons processed by the MAC layer. Therefore, the vehicles suffer less fierce contention based on the EDCA mechanism. The queuing delay and the packet loss rate of the periodic beacons in the MAC layer are shortened. It should be noted that the rate is not enlarged without restrictions, which ensures that vehicles can obtain prompt information from the surrounding vehicles. Figure 8 shows that the calculated

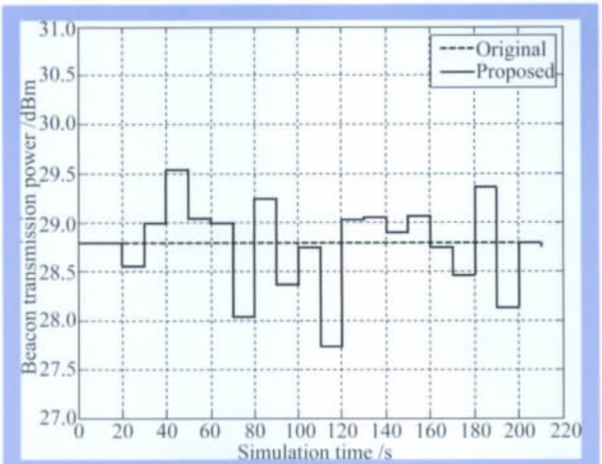

Fig.8 Comparison of beacon transmission power

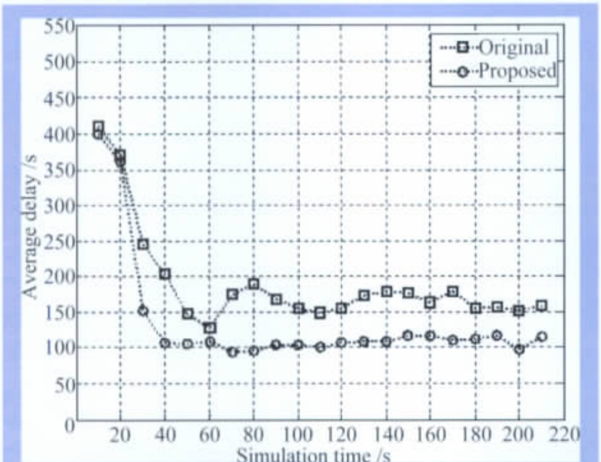

Fig.9 Comparison of average delay of the vehicular network

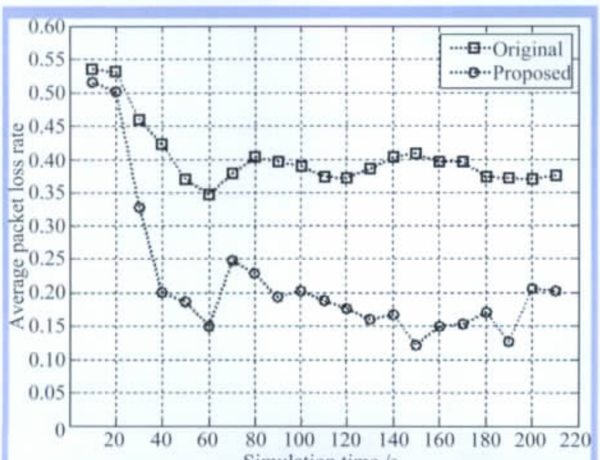

Fig.10 Comparison of average packet loss rate of the vehicular network

values of the beacon transmission power are almost a little lower than the original values. The transmission power will determine the coverage range of each vehicle, and then affect the number of competitive vehicles in its communication range. So the lower transmission power can further weaken the contention in the MAC layer, and the beacon loss rate and delay performance can be guaranteed.

In short, our proposed architecture is effective to adjust the beacon transmission rate and power dynamically while maintaining the lower packet loss rate and shorter delay of beacons, which outperforms the original one. The transmission delay and the packet loss rate of the periodic beacons are suppressed at a lower level by utilizing the proposed scheme. Moreover, the packet loss rate is reduced significantly which is suppressed below 25%.

4.2 Reliability analysis under different vehicle densities

As we know, the high speeds of vehicles and the frequently changed network topology are the main characteristics of the vehicular networks. In this section, we want to simulate three vehicle scenarios under different density configurations to further validate our proposed architecture.

We study three scenarios for extensive simulations in this section. Every scenario have a square area with 1 km side, thus the simulated field covers an area of × 10 001 000 m^2. Scenario A is a rectangle road network, where the number of cars varies from 16 to 39 according to different vehicle intervals. Scenario B shows a rectangle road network with 9 intersections, where the number of cars varies from 21 to 54. In Scenario C, the topology of the road is a 3 × 3 grid network. Accordingly, the number of cars changes from 26 to 43. The detailed parameters of the three scenarios are illustrated in Table IV.

During the simulation, in order to count the packet loss rate due to congestion, we ignore the

Table IV Parameters used in simulation

Parameter	Value		
	Scenario A	Scenario B	Scenario C
Simulation environment area/ m^2	1 000 × 1 000		
Width of road/ m	5	5	5
Number of intersection	4	9	16
Average interval between vehicle/ m	500 400 300 200		
Number of cars	16/19/26/39	21/27/3 654	26/32/43
Number of lane per road	2	2	2
Size of UDP packet/ Byte	100 ~ 1 000 Exponential distribution with mean 500		
Size of beacon frame/ Byte	156	156	156
Simulation time/ s	200	200	200

lost packets due to the long distance where vehicles cannot communicate with each other. We show the relationship between the vehicle distance and the transmission power in Figure 11. We can see from Figure 11 that the relative distance between the two vehicles varies with their moving. Different settings of the transmission power result in different maximum communication distances between vehicles. For example, if we adopt a Rayleigh channel, the 26.5 dBm transmission power means that the maximum communication distance of vehicles is 800 m. 27.1 dBm power corresponds to 830 m communication range, and 28.5 dBm corresponds to 1 030 m.

After the extensive simulations under different road scenarios and different vehicle densities, we attain the optimal beacon rate-power pairs corresponding to the vehicles' density, shown in Table V. Then, we plot the performance comparison curve with our mechanism and the original one, shown

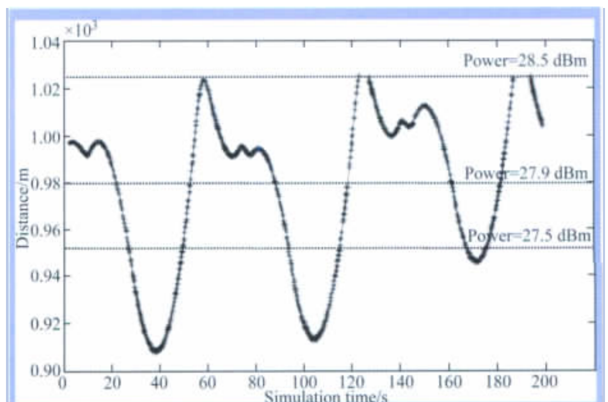

Fig.11 The distance between two randomly selected vehicles

in Figures 12 to 14. From Figures 12 to 14, we can find that under different road models, the growth of vehicle density leads to higher packet loss rate. Through the adjustment of the beacon rate and power, the average packet loss rate can be reduced by half, which validates that our proposed architecture outperforms the original one.

Table V Optimal beacon rate-power with different densities

Guide value	Density /(cars • km^{-2})									
	16	19	21	26	27	32	36	39	43	54
Rate/ ms	122.0	125.5	123.6	125.5	126.2	125.0	124.9	123.4	125.1	124.5
Power/ dBm	28.5	28.4	28.5	28.4	28.7	28.5	28.3	28.1	28.3	28.6

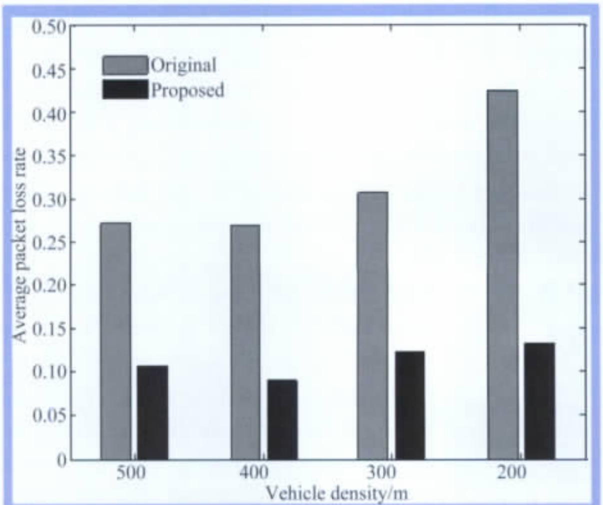

Fig.12 Comparison of average packet loss rate in Scenario A

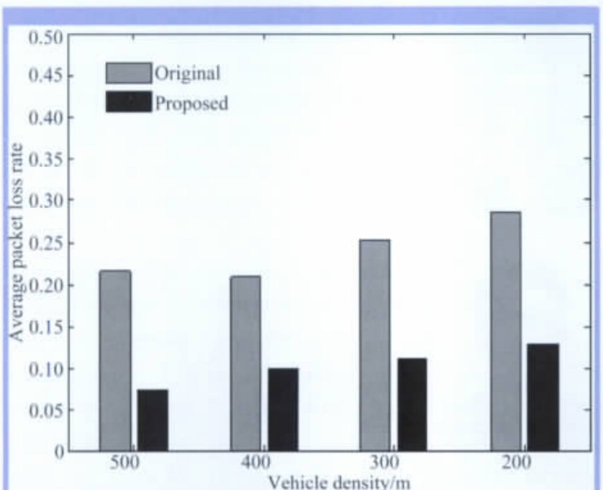

Fig.13 Comparison of average packet loss rate in Scenario B

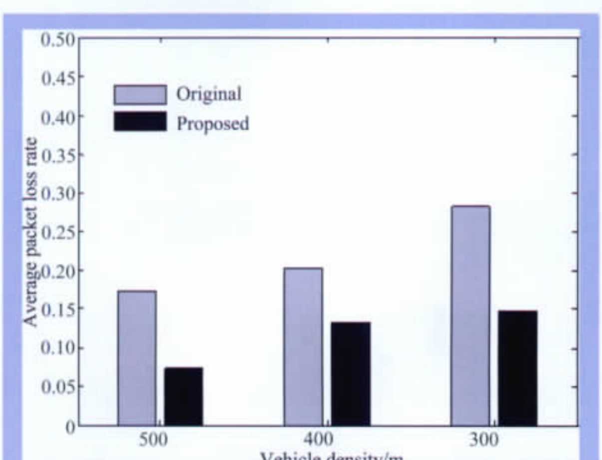

Fig.14 Comparison of average packet loss rate in Scenario C

V. CONCLUSIONS

The term IoT has recently become popular to emphasize the vision of a global infrastructure of networked physical objects. As a representative of IoT applications, VANETs aims to provide much safer public transportation and enhanced driving experience, vehicles in VANETs employ periodic beacons related with traffic safety broadcasting for status advertisement. In this paper, we proposed a cross-layer safety-critical broadcast service architecture integrating VANET with 3G networks to adjust the beacon transmission rate and power dynamically according to the current traffic situation, while maintaining the required QoS. The extensive simulation results show that with the pair of guide beacon transmission rate-power generated by back propagation algorithm, the performance in terms of packet loss rate and transmission delay can be improved significantly. The analysis of scenarios with two or more RSUs will be our future work.

Acknowledgements

This work was supported by the 111 Project under Grant No. B08004; the major project of Ministry of Industry and Information Technology of the People's Republic of China under Grant No.2010ZX03002-006 and China Fundamental Research Funds for the Central Universities. The authors would also like to thank anonymous reviewers for their constructive comments that have significantly improved the quality of this paper.

References

[1] ATZORI L, IERA A, MORABITO G. The Internet of Things: A Survey[J]. Computer Networks, 2010, 54(15): 2787-2805.

[2] IEEE P802.11pTM/D10.0. IEEE 802.11[S] Working Group of the IEEE 802 Committee, January 2010.

[3] IEEE P1609.0TM/D0.8[S]. Draft Standard for Wireless Access in Vehicular Environments (WAVE)-Architecture, May 2009.

[4] LEQUERICA I, RUIZ P, CABRERA V. Improvement of Vehicular Communications by Using 3G Capabilities to

Disseminate Control Information[J]. IEEE Network, 2010, 24(1): 32-38.

[5] TORRENT-MORENO M, MITTAG J, SANTI P, et al. Vehicle-to-Vehicle Communication: Fair Transmit Power Control for Safety-Critical Information[J]. IEEE Transactions on Vehicular Technology, 2009, 58(7): 3684-3703.

[6] SCHMIDT R, LEINMULLER T, SCHOCH E, et al. Exploration of Adaptive Beaconing for Efficient Intervehicle Safety Communication [J]. IEEE Network, 2010, 24(1): 14-19.

[7] YE F, YIM R, ROY S, et al. Eficency and Reliability of One-Hop Broadcasting in Vehicular Ad Hoc Networks[J]. IEEE Journal on Selected Areas in Communications, 2011, 29(1): 151-160.

[8] FALLAH Y, HUANG C, SENGUPTA R, et al. Analysis of Information Dissemination in Vehicular Ad-Hoc Networks With Application to Cooperative Vehicle Safety Systems[J]. IEEE Transactions on Vehiclular Technology, 2011, 60(1): 233-247.

[9] HUANG C, FALLAH Y, SENGUPTA R, et al. Adaptive Intervehicle Communication Control for Cooperative Safety Systems[J]. IEEE Network, 2010, 24(1): 6-13.

[10] WANG C, LIN T, CHEN J. A Cross-layer Adaptive Algorithm for Multimedia QoS Fairness in WLAN Environments Using Neural Networks [J]. IET Communications, 2007, 1(5): 858-865.

[11] WANG C, LIN P, LIN T. A Cross-layer Adaptation Scheme for Improving IEEE 802.11e QoS by Learning[J]. IEEE Transactions on Neural Networks, 2006, 17(6): 1661-1665.

[12] DU Y, ZHANG L, FENG Y, et al. Performance Analysis and Enhancement of IEEE 802.11p/1609 Protocol Family in Vehicular Environments [C]// 13th International IEEE Conference on Intelligent Transportation Systems: September 19-22, 2010, Funchal. IEEE 2010: 1085-1090.

[13] BERNARDOS C, FESTAG A, MAXEMCHUK N, et al. Advances in Vehicular Communications Networks [J]. IEEE Network, 2010, 24(1): 4-5.

[14] WANG S, CHOU C. NCTUns Tool for Wireless Vehicular Communication Network Researches [J]. Simulation Modeling Practice and Theory, 2009, 17(7): 1211-1226.

Biographies

Zhang Lin, Ph. D., associate professor. Dr. Zhang got both his B. S. and Ph. D. degree from Beijing University of Posts and Telecommunications (BUPT), China, in 1996 and 2001, respectively. He was a postdoctoral researcher in Information and Communications University, Korea from Dec. 2000 to Dec. 2002. He went to Singapore and held a Research Fellow in Nanyang Technological University, Signapore from Jan. 2003 to June. 2004. Since June 2004, he has been working at BUPT as a lecturer and then an associate professor. He is now deputy dean of Graduate School at BUPT. His research interests are information theory, QoS and policy control in networks and mobile Internet. He has published more than 20 papers in IEICE, ETT and Springer journals.

Liu Yu, Ph. D., associate professor. Dr. Liu received her B. S. degree in automatic control and Ph. D. degree in signal and information processing both from Beijing University of Posts and Telecommunications (BUPT), China. Her main research areas include compressive sensing, distributed source coding, and information processing in wireless networks.

Wang Zi, is supposed to receive her M. S. degree in signal and information processing from Beijing University of Posts and Telecommunications, China in 2012. Her research interests include wireless sensor networks, mobile adhoc networks and vehicular networks.

Du Yingtian, received his B. S. degree in information engineering and M. S. degree in signal and information processing from Beijing University of Posts and Telecommunications, in 2008 and 2011, respectively. His research interests include wireless communications in intelligent transportation system and neural networks.