GeRA: Generic Rate Adaptation for Vehicular Networks

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***Abstract*—Vehicular networks are novel wireless networks particularly for inter-vehicle communications. In vehicular networks, the current rate adaptation algorithms are not applicable to the new situations (e.g., high mobility, SNR fluctuation and complicated environment). We propose a novel hybrid rate adaptation scheme named as GeRA (Generic Rate Adaptation). The key idea of this scheme is to make use of both context information and signal strength information to estimate current channel condition in a much more efficient and accurate way. GeRA dynamically and adaptively switches the rate selection resources between our well-designed context information empirical model and SNR prediction model according the current situation to achieve the high mobility, density and variation. In our extensive empirical experiments and performance evaluation, we compare this scheme with two types of rate adaptation algorithms and one latest vehicular networks rate adaptation. Our experiments in real vehicular environment show that GeRA performs better than other choosing algorithms under different mobility scenarios, different traffic density and different cross-layer protocols. Our scheme achieves significant higher goodput than traditional rate adaptation algorithms, up to 93%. Compared to the context information based algorithm, GeRA also has better performance in most scenarios.**

Keywords-generic rate adaptation; context informaiton; SNR; vehicular networks

I. INTRODUCTION

VANET (Vehicular Ad Hoc Network) is a subclass of MANETs (Mobile Ad Hoc Networks). It is a new approach with advantages as low latency, direct communication, broader coverage and charge free to achieve better communications and traffic management among vehicles [20]. In 2003, ASTM and IEEE adopted the Dedicated Short Range Communication [1] standard (ASTM E 2213-03) [2] which provide wireless communications capabilities for transportation applications within a 1000 meters range at typical highway speeds and provide seven 10 MHz channels at the 5.9 GHz licensed band for Intelligent Transportation Systems [3. The increasing multi-rate technology leads to a question: how can we choose one proper transmission rate from the extended rate range? One possible way is to employ the rate adaptation. Rate adaptation is to estimate real-time link quality, then select the optimal transmission rate to obtain the maximum throughput all the time.

To achieve the goals of rate adaptation, many works have been conducted. One category of the methods is the transmitter-based rate selection schemes, e.g., ARF [5], AARF [6], CARA [7], Samplerate [8], RARA [9], which use packet statistics to estimate current channel condition. Another category of the methods is the receiver-based ones, e.g., RBAR [10] and OAR [11], depending on SNR for the adaptation algorithms.

Compared to traditional wireless networks, vehicular networks have the following unique features bring great challenges to make the current rate adaptation methods not work well.

1) High mobility

Vehicle's moving speed is always much higher than the nodes in traditional wireless networks [12]. The unprecedented high mobility of vehicular networks brings a big challenge to the channel condition. The channel condition can be significant changed in very short time, which requires very tiny delay between channel estimation and rate selection. High mobility also results in the intermittent connection between vehicles.

2) SNR fluctuation

High fluctuation of SNR is obvious in vehicular networks. The difference between consecutive SNR values can be as large as 10 dB. When the vehicle situation suddenly changes, such as the vehicle acceleration, direction changing, or neighbor vehicle location changing, they may cause significant SNR fluctuations which result in high error rate when using pure SNR-based or pure context information based rate adaptation algorithms.

3) Complicated environment

In vehicular networks, both the transmitter and the receiver are outdoors, suffering from the weather condition, traffic jam, tall building obstacle and reflection of signals [12]. Because vehicles move fast through different scenarios, and the complicated channel condition variation makes us hard to precisely measure and describe them in empirical models, those model-based rate adaptation schemes designed for the VANET hard be used for every environment condition, and at the same time building

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empirical model for all situation will cost a lot of training efforts and computations.

Even in the VANET, a category of model-based algorithms, CARS and MTRA, are proposed, which utilize the context information (distance and relative velocity) to build empirical models, and then conduct the rate selection. But this category of methods needs a lot of training efforts to get the model and results in high computation cost and low scalability.

To solve the challenges brought by VANET, we do need a new approach, which should be more efficient, accurate and generic to different environments.

In vehicular networks, one of the unique characteristics is the context information of vehicles. Context information consists of information about the environment that is available to the vehicle, such as the position, speed and acceleration. We can obtain that information from a GPS device and employ wireless devices to periodically broadcast the locations and receive the location information from neighboring vehicles. When we exam the context information and transmission data from a large scale taxi dataset collected from a large city in China [12], we have an interesting observation that data transmission is critical relative to the context information. Based on the real data varying the distance and speed, we obtain an empirical model of distance, speed and goodput (the application level throughput), which can describe the relationship between context information and transmission data. Hence, based on this interesting observation, we propose the following novel method to achieve generic rate adaptation for vehicular networks.

In this paper, we introduce a new Generic Rate Adaptation algorithm (GeRA) utilizing both context information and SNR value as the complement methods for each other. We switch between context information model and SNR table dynamically, avoiding the inaccurate estimation in dramatically changing environments as conducted in the previous works.

The three main advantages of GeRA are as follows. First, GeRA does not need much implement cost, but can achieve short delay and high Goodput in vehicular networks. We employ SNR value to catch up with the fast changing channel condition in vehicular networks, and solve the slow response and inaccurate evaluation problems in the existing schemes without incurring the overhead of RTS/CTS. We also apply SNR prediction to gain much more accuracy in channel quality estimation. Second, GeRA is robust to collisions from the hidden nodes. Both of context information and SNR values are orthogonal to collisions. Third, GeRA has quick response. When the data transmission begins, this scheme can quickly make rate selection without sending probing packets or do not have any communication history in a recent time window.

In a summary, the main contributions of this paper are below.

- We utilize the dynamic switching between context information and SNR based selection to solve the high dynamic, SNR fluctuation and environment challenges.
- We have the relationship model describing the context information and Goodput.
- We employ real dataset to evaluate GeRA, and show that GeRA performs much better than several rate adaptation algorithms in terms of efficiency, scalability and Goodput.

II. Related Work

A. *Transmitter and statistics-based method*

ARF [5] and AARF [6] adapt the transmission rate as the met threshold of frame reception. ONOE [13] gives credits to those transmission rates that incur less retransmission. By using average number of retries, CARA [7] also base on frame statistics information. SampleRate [8] is a bit-rate selection algorithm that probes higher bit-rates. RRAA [14] shortens the delay caused by the large estimation window size by using short-term loss ratio.

B. *SNR-based method*

After the first receiver-based rate adaptation algorithm RBAR [10], OAR [11] uses RTS/CTS exchange, which may cause transmission overhead. In RARA [9], the receiver notifies the sender to increase or decrease transmission rate through regulating transmission rate of ACK frame, which is also not supported by standard 802.11 protocols. Since 2008, researchers proposed to directly get the SNR information at the transmitter so that the RTS/CTS overhead can be eliminated, e.g., CHARM [15] and SGRA [16]. As we discussed above, the challenges in VANET make the above two categories not work well.

C. *Model-based method*

As the demand for high-bandwidth application in vehicular wireless networks keeps increasing, some novel algorithms that can adapt to fast-changing channel quality have been proposed, such as CARS [17] and MTRA [18]. They choose to predict channel quality with context information. CARS features the use of context information such as transmitter-receiver distance and relative velocity, it conducts a set of outdoor experiments to build an empirical model which reflects the relationship between PER (packet error rate) and context information. MTRA is a self-adaptive model-tree-based rate adaptation in vehicular networks. It uses the decision tree induction algorithm to predict BER and selects the optimal rate. But this category of methods is hard to achieve great efficiency, scalability and high goodput because they need tremendous training efforts due to environment changing.

III. GeRA: Generic Rate Adaptation

In this section, we first introduce the overview of our novel generic rate adaptation scheme. Second we successively present the context information empirical model, SNR prediction model and the hybrid rate selection algorithm separately.

A. GeRA Overview

Our scheme aims at maximizing the goodput, which heavily depends on the ability to accurately and efficiently predict the channel quality. To tackle the challenges from the high mobility, SNR fluctuation and complicated environment in VANET, we utilize the context information and SNR value to estimate the channel condition and adapt to the changing environment.

As shown in Fig. 1, GeRA consists of three main components: empirical context information model, SNR prediction model, and hybrid rate selection algorithm. GeRA works as follows: First, the empirical model obtains the context information from the application layer and provides output to the rate selection algorithm. Second, with data transmission, SNR prediction model accumulates knowledge about the relationship between SNR and the transmission rate obtained from 802.11 Wireless Firmware. Last, the hybrid rate selection algorithm dynamically makes the rate adaptation from the outputs of the above two models. When a vehicle initially transmits data, the empirical context information model comes to work, and then the data adaptation utilizes SNR prediction model to achieve much more accurate and scalable performance.

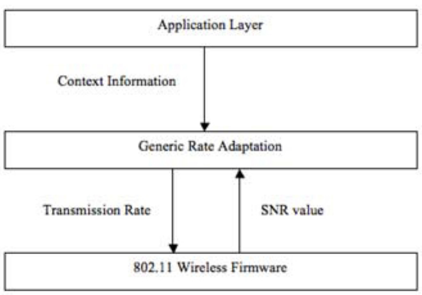

Figure 1: Scheme Structure

B. Empirical Context Information Model

Context information is defined as the environment information that can imply the channel quality and is available to vehicles. It includes vehicle position, speed, and acceleration that are obtained by GPS devices. So a vehicle can compute the distance and relative speed to the target vehicle in a low cost way.

To use context information in link-layer rate adaptation, we need to build the model of context information, transmission rate and the resulted goodput. We consider the distance and relative speed to construct the model, which are the most significant factors of goodput according to our realistic datasets.

Note that there are already several analytical and empirical models for radio frequency (RF) propagation in free space. The free space path loss model and the ray propagation model can be used to model the effect of distance. The delay tap model or ray models with delay profiles [19] can be used to model the effect of speed. However, none of them are devised of modeling the collective effects of distance and speed. Hence we conduct empirical experiments to develop the model describing the relationship among distance, speed, and the goodput. In the experiments, we vary the distance from 0 to 250 meters and speed from 0 to 100 kmph for each usable link layer bit-rate and recorded the resulted goodput. Fig. 2 plots the relationship between context information and goodput for bit-rate 54M.

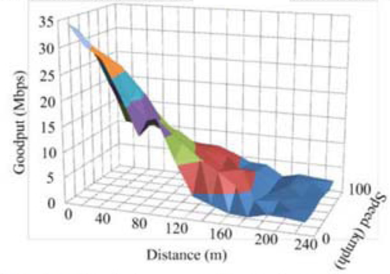

Figure 2: Relationship between context information and goodput

From our experiments, we find that the high speed and long distance require a low transmission bit-rate in order to maintain a better goodput. Because in such a harsh environment, the high transmission rate tends to the low SNR at the receiver and most of the data frames cannot be decoded successfully. But for the low speed and short distance, we can achieve high transmission rate.

C. SNR Prediction Model

Context information can help vehicle to select transmission rate before knowing well about the environment. However, in VANET, the channel condition varies so fast due to the multi-path effect, obstacles, weather conditions, and background interference. Such a complicated communication channel is hard to be precisely modeled. Fortunately SNR is a good measure of channel quality because theoretically the relationship between SNR and BER is well-known across various bit-rates. Therefore, SNR can be employed to estimate the vehicle that picks the optimal bit-rate to maximize goodput. Moreover, SNR can be estimated on every frame reception so that it operates on an enough short timescale to combat fast channel quality variations.

Every vehicle maintains a table about the relationship between goodput, g, and (rate, SNR) pairs. In 802.11 standards, there are 8 usable bit-rates, denoted by $\{r_1, r_2 \ldots r_8\}$. And the channel SNR is typically in the range of 0 to 60. We divide this range into 12 equally sized partitions, denoted by $\{s_1, s_2 \ldots s_{12}\}$. In this way, the table has a total of 96 entries, each of which relates the expected goodput to a (r_i, s_j) pair, where $1 \leq i, j \leq 12$. In particular, $g_{ri,sj}$, defined as the expected goodput when the frame is transmitted at rate r_i and SNR s_j, is given by

$$g_{ri,sj} = \frac{d_{ri,sj}}{t_{ri,sj}} \tag{1}$$

Intuitively, the table should be updated for every successful frame transmission. Assuming SNR symmetry at the transmitter and receiver, we can estimate the channel's SNR whenever an ACK frame is received. If the frame is successfully received at its first transmission, then let D be the length of the transmitted frame and T be the air time used for transmission at (r_i, s_j). The table then is updated in the following way:

$$g_{ri,sj} = \frac{d_{ri,sj} + D}{t_{ri,sj} + T} \quad (2)$$

A subtler problem is when the frame fails one transmission attempt. In this case, the instant SNR is not available since no ACK is received. We choose to still update the table with a previous recorded SNR and let D, the length of the frame, be zero. The table is then updated by

$$g_{ri,sj} = \frac{d_{ri,sj}}{t_{ri,sj} + T} \quad (3)$$

Note that T, the air time including both the time used for transmission and the back-off time, is given by,

$$T = T_{transmission} + T_{back-off} \quad (4)$$

D. Hybrid Rate Selection Algorithm

The algorithm consists of two parts. First, when the SNR table is empty, GeRA will simply consult the model of context information to find out the most promising rate for transmission. Let *F (distance, speed, rate)* represent the model and d be the distance to the receiver and s be the relative speed. Then r^*, the selected transmission rate, is given by

$$r^* = \arg\max_{r\in\{r_1, r_2 \cdots r_{12}\}} (M(d,s,r)) \quad (5)$$

If the frame transmitted at this rate fails, the algorithm will choose the next lower rate for retransmission and so on.

Second, if the vehicle is equipped with up-to-date SNR information, then it will first predict the SNR and then consult the SNR table to find the most promising transmission rate. Since in vehicular networks SNR value often has high fluctuations, it is much more difficult than in WLAN to predict the future SNR. LWMA (Light Weighted Moving Average) and EWMA (Exponentially Weighted Moving Average) used in previous rate adaptations works, both cannot handle the high fluctuation and irregularities in observed SNR. Hence we choose to combine the moving averages and the deviations to predict a conservative SNR value for the next transmission. Let s_{ave} be the average SNR, s_{cur} be the current SNR and s_{dev} be the deviation in observed SNR. Then the average SNR is given by

$$s_{ave} = (1-a)s_{ave} + as_{cur} \quad (6)$$

And s_{pdt}, the predicted SNR, is given by

$$s_{pdt} = s_{ave} - bs_{dev} \quad (7)$$

Where

$$s_{dev} = (1-c)s_{dev} + c\,|\,s_{cur} - s_{ave}\,| \quad (8)$$

Note that a, b, c are design parameters. According to our experience, we choose the following values: a=0.1, b=0.9, c=0.1. Let *B(SNR, rate)* be the SNR table. With the predicted SNR, the vehicle can now look up the table and select the best transmission rate by

$$r^* = \arg\max_{r\in\{r_1, r_2 \cdots r_{12}\}} (B(s_{pdt}, r)) \quad (9)$$

IV. EMPERICAL EXPERIMENTS AND PERFORMANCE EVALUATION

We compare our novel hybrid algorithm with three reference rate adaptation algorithms, namely AARF, RBAR, and MTRA which each represents one main category of latest methods, such as the Transmitter-statistics-based (AARF), Receiver-SNR-based (RBAR), and context-information-based (MTRA).

The results are from empirical experiments with 802.11a installed on two test vehicles. We use 802.11a because their parameters are very similar to 802.11p (the standard for vehicular networks but still not realized in vehicular networks).

A. Evaluation Methodology

We employ the following metrics to evaluate the rate adaptation algorithms. Goodput is defined as the average number of bits transmitted successful per second. Our objective is to maximize the goodput by adapting the transmission rate to varying channel condition. Successful transmission is defined as the aggregate number of packets that are successfully transmitted for all the vehicles in the total communication time. Average transmission time is defined as the average transmission time used for delivering a single packet, including the backoff and the retransmission time. Successful transmission to rate distribution: the successful transmitted packets are classified according to the rate used for transmission.

B. Evaluation under Different Vehicle Speeds

In vehicular networks, vehicle speed is an important factor that can seriously affect the performance of rate adaptation algorithms. We vary the velocity value from 8 mps to 28 mps, which is approximately equal to 30 kmph and 100 kmph respectively. This velocity range is very close to the case where vehicles move in urban environment.

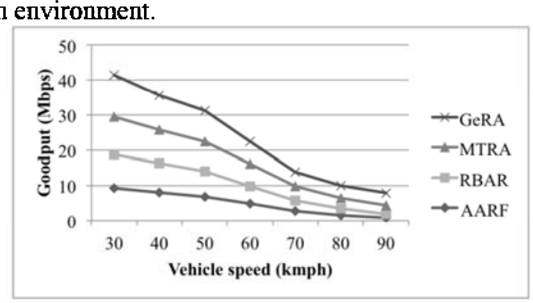

Figure 3: Goodput with increasing vehicle speed in vehicle to infrastructure

In Fig. 3, all algorithms perform worse as the speed increases. When the vehicle speed is low, GeRA performs much better than other algorithms. This is because when the speed is low, the time duration that vehicles are in the transmission range is much longer, hence the total communication time is longer. For example, although at the beginning of the transmission GeRA and MTRA both use the context information for rate selection and thus have comparable goodput performance, as the time goes by GeRA changes to use SNR information for rate selection, which can generate better performance. Therefore, on average GeRA can outperform MTRA. It is clear that AARF and RBAR both produce much lower goodput than GeRA and MTRA. AARF slowly respond to channel changing due to higher and higher rate update threshold, it is too conservative to use any higher data rate. The overhead caused by RTS/CTS exchange seriously influences the performance of RBAR. In vehicle-to-vehicle scenario, the experiments show similar results.

C. *Evaluation under Different Cross-layer Protocols*

Most previous works only consider maximize goodput at the Link Layer. The assumption behind is that the higher the goodput at the Link Layer, the higher the goodput at the Application layer. However, this is not true in many cases. If the transmission rate at the link layer varies significantly in the range of (6 to 54Mbps), this rate variability can cause TCP working inefficiently.

After comparing the performance in TCP and UDP scenarios, from Fig. 4 and Fig. 5 we can conclude that in both TCP and UDP scenarios, GeRA works well.

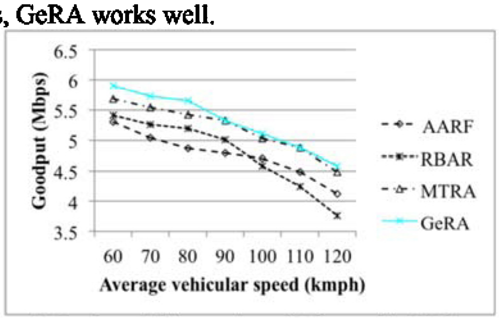

Figure 4: Goodput with increasing vehicle speed in UDP scenario

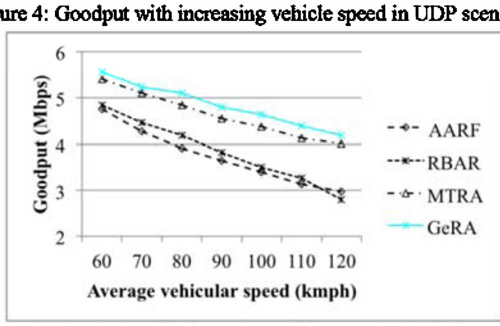

Figure 5: Goodput with increasing vehicle speed in TCP scenario

V. CONCLUSION

In this paper, we proposed a hybrid rate adaptation scheme (GeRA) to tackle the challenges from rate adaptation in vehicular networks. GeRA performs better than the latest AARF and RBAR rate adaptation schemes, and outperforms MTRA vehicular network rate adaptation scheme. This hybrid scheme is proved to have better performance than history statistics-based, SNR-based and empirical model-based schemes. In future, we will test GeRA in much more scenarios. The accuracy of channel condition prediction needs to be improved further.

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