QoS sensitive VANET Control Scheme based on Feedback Game Model

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Abstract

As a special type of mobile ad-hoc network, Vehicular Ad-hoc Network (VANET) is considered as an attractive topic by many researchers. In VANETs, vehicles act as routers and clients, which are connected with each other through unreliable wireless links. Due to the dynamic nature of vehicles, developing communication protocols for VANETs is a challenging task. In this paper, we tackle the problem of real-world VANET operations and propose a new dual-level communication scheme through the combination of power and rate control algorithms. Based on the game theoretic approach, the proposed scheme effectively formulates the interactive situation among several vehicles. With a simulation study, it is confirmed that the proposed scheme can achieve better performance than other existing schemes under widely diverse VANET environments.

Keywords: Vehicular Ad hoc Network, Game theory, Power control, Packet rate adaptation, Feedback mechanism.

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1. Introduction

Over the past few years, Vehicular Ad-hoc NETwork (VANET) introduced unique attractive features and a plethora of potential applications. Therefore, inter-vehicle communication has gained a tremendous amount of attention from wireless networking and automotive industries. In particular, VANET based inter-vehicle communication is believed on its promise in traffic safety, efficient driving and traffic operation enhancement at low cost. To bring its potency to fruition, VANET has to cope with formidable challenges. First of all, applications stringently require the robust message delivery and frequent data exchanges to share of various real-time road and traffic information. However, the dynamics of the network topology causes a lack of link connectivity and frequent fragmentations. For this reason, the current research on VANETs has been focusing on the development of adaptive communication algorithms while preventing network congestions [1-3].

Due to the high mobility of vehicles, the communication link between two vehicles might remain active for only a short amount of time. Therefore, reliability is an extremely important factor for VANET applications. One way of making reliable vehicle-to-vehicle link connections is to increase the transmission power. However, the high transmission power results in the high network overhead. If the transmission power is low, it tends to cause excessive multi-hop communication packets with a long delay. Therefore, a fixed transmission power cannot provide an effective solution for the VANET management. Dynamic adaptation of transmission power is crucial to ensure effective network operation despite changing network conditions [4].

With the adaptive power control, some emergency messages in VANETs should be delivered in a timely and accurate manner. For example, messages related to accidents must be propagated to the target region on time to avoid potential secondary accidents. Therefore, it is highly desirable for emergency messages to have higher priority over other messages. To implement this mechanism, VANET systems should support message differentiations. Similar to the Quality of Service (QoS) differentiation in the contention-based channel access, different priority levels should be assigned to various messages in VANETs according to their urgency or delay requirements [5]. To provide QoS for different categories of traffic services, we use IEEE 802.11e, which is a complement to the IEEE 802.11 family for the MAC layer level. By using Contention Window (*CW*), this protocol can provide proportional service differentiation in VANETs in terms of delay by prioritizing messages [6, 7].

Due to the complexity of mobility, unpredictability of link quality, varying topology and message differentiations, traditional end-to-end communication methods have met with limited success when applied to VANETs. In addition, many inter-vehicle communication techniques involve autonomous decision-makers (i.e., vehicles) with conflicting objectives. Each vehicle independently makes behavioral choices in the context of a dynamic environment that is formed by the collective actions. To understand the behavior of self-regarding vehicles, game theory can be used. Game theory is a field of applied mathematics for modeling the interactions of independent agents. It can describe the possible reactions to the actions of the other agents and analyze the situations of conflict and cooperation. Currently, game theory is widely adopted as an important tool for modeling of distributed systems and cross layer optimization [8].

Though game theory was invented to explain complicated economic behavior, it has been widely recognized as an important tool in the research of network design. Some promising potential applications of game theory in wireless mobile networks are power control, bandwidth pricing, resource sharing, an incentive mechanism for cooperation between mobile nodes, the access control to a common radio channel, and auctions for wireless bandwidth. In recent years, these issues have become an increasingly important part of VANET operations. In applying game theory for VANET operations, critical control problems can be well solved within the game theoretical framework.

Motivated by the facts presented in the above mentioned discussion, we develop a new game-based VANET communication scheme to adaptively control the power and packet rate. The proposed scheme combines adaptive transmission power and packet rate control mechanisms into one single algorithm loop. By taking into account the mutual effect of power and packet rate, our integrated scheme can approximate an optimized network performance in a cross layer approach. The important features of the proposed scheme are i) dynamically adjustable approach with considering the current VANET situation, ii) an entirely distributed fashion for practical implementation, iii) adaptively interactive process based on the feedback model, iv) relevant tradeoff between different objectives. Under widely different and diversified traffic situations, the proposed scheme can measurably get the better VANET performance during real world network operations.

Usually, traditional game theory implicitly assumes that players are rational and have complete information about the game situation throughout the time period. However, this assumption is obviously not satisfied under the real world environment; experiments have shown that players do not always act rationally. However, our game based interactive approach can adaptively approximate an efficient solution without unrealistic rationality requirement. It is a main contribution of this work for the VANET management.

This paper is organized as follows. Section II gives a brief description of related work. Section III presents the proposed algorithms in detail. In Section IV, performance evaluation results are presented along with comparisons with the *PCJA* and the *JPRC* schemes proposed in [5] and [12]. Through simulation, we show the ability of proposed scheme to achieve high accuracy and promptness in dynamic VANET environments. Finally, concluding remarks are given in Section V.

2. Related Work

Recently, several communication schemes have been presented for VANET systems. The *Fair Transmit Power Control* (*FTPC*) scheme [9] is designed to prevent accidents by providing accurate, up-to-date local status and hazard information to the driver. This scheme demonstrates the importance of transmit power control for avoiding saturated channel conditions while ensuring best use of the channel for safety-related purposes. To control the load of periodic messages on the channel, the *FTPC* scheme adopts a distributed transmit power control method based on a strict fairness criterion.

The *Feedback Based Power Control* (*FBPC*) scheme [10] considers the problem of adjusting transmission power for vehicle-to-vehicle broadcast safety communication in vehicular ad hoc networks. Given a target communication range designated by a vehicle safety application, the power control algorithm in the *FBPC* scheme is developed to select a transmission power no greater than necessary for the targeted range. This power control algorithm results in higher communication reliability since collisions are minimized for safety communications. The main idea of *FBPC* scheme is to add a power tuning feedback beacon during each safety message exchange.

The work in [11] studies the effects of adapting the beacon rate with respect to reduced accuracy and changing offered load. Considering both offered load and corresponding accuracy, many different schemes have been developed for adapting the beacon rate according to the traffic situation. Requirements for minimum and maximum beacon rate are introduced which define the boundaries for the adaptation process. The aggregation result increases the beacon rate dynamically, starting from the minimum required rate.

The *QoS Constraint Multimedia Communication* (*QCMC*) scheme [18] is an energy-efficiency model for multiple input–multiple-output orthogonal frequency-division multiplexing (MIMO-OFDM) mobile multimedia communication systems with statistical QoS constraints. This scheme uses a statistical exponent to measure the queue characteristics of data transmission in wireless systems, and simplifies the complex multichannel joint optimization problem as a multi-target single-channel optimization problem. Moreover, a novel algorithm is designed to improve the energy efficiency of MIMO-OFDM mobile multimedia communication systems. Finally, the *QCMC* scheme derives a closed-form solution for the energy efficiency optimization process.

The *Power and Contention window Joint Adaptation* (*PCJA*) scheme is a new algorithm for dynamic adaptation of transmission power and contention window size to enhance performance of VANETs [5]. This scheme uses a joint approach to adapt transmission power at the physical layer and QoS parameters at the MAC layer. Based on the estimated local vehicle density, the transmission power is adapted to change the transmission range dynamically, while the window size is adjusted according to the instantaneous collision rate to enable service differentiation.

The *Joint Power and Rate Control* (*JPRC*) scheme focuses on analyzing and understanding the fundamental implications of adapting power and rate on the reception performance [12]. The *JPRC* scheme uses the average packet inter-reception as a metric for reception performance and evaluates it with respect to sender-receiver distance. The main advantage of this approach is to efficiently approximate an optimal power level under a given channel load target while reducing complexity.

As described above, extensive research has been carried out on numerical methods or algorithms for vehicle-to-vehicle based wireless communications, and has received a lot of attention in recent years. These existing schemes concern the enhancement of multimedia information exchange rate, and the reduction of the traffic impact on the environment. In the near future, these technologies will also allow the design of routing protocols that offers low communication overhead, low time cost and high adjustability for city, highway and rural environments.

3. Proposed VANET Communication Algorithms

In this section, the proposed VANET communication scheme is introduced. In the individual and parallel execution manner, the proposed scheme can suitably adapt to the fast changing VANET environments. Compared with the traditional communication algorithms, we explain why our approach yields the effective performance under the highly dynamic network topology and message broadcasting nature.

3.1 Power Control Algorithm for VANETs

Interactions between vehicles involving a heavy exchange of messages to properly perform a task are a common in VANET communications. Therefore, the Communication Range (*CR*) is a critical parameter to enable wireless communications in a short time. If all vehicles act greedily by maximizing their range, the message will reach its destination in less number of hops. However, it causes the expense of the increased co-channel interference. As a consequence, more vehicles will contend simultaneously at every point for using the same channel, which may collapse due to increased collisions. On the contrary, if all vehicles communicate each other by minimizing their range, it will result in more communication hops and a large packet delay, which might not be acceptable for a lot of applications. Therefore, a fixed transmission range cannot adapt the rapid change of traffic conditions and would lead to severe degradation to the VANET performance. To take advantage of power saving and increased capacity, we develop a new dynamic VANET power control algorithm, which can find the best transmission range. This approach is an effective way to maintain communication connectivity while minimizing the adverse effects of a high transmission power. This situation is represented in **Fig. 1**.

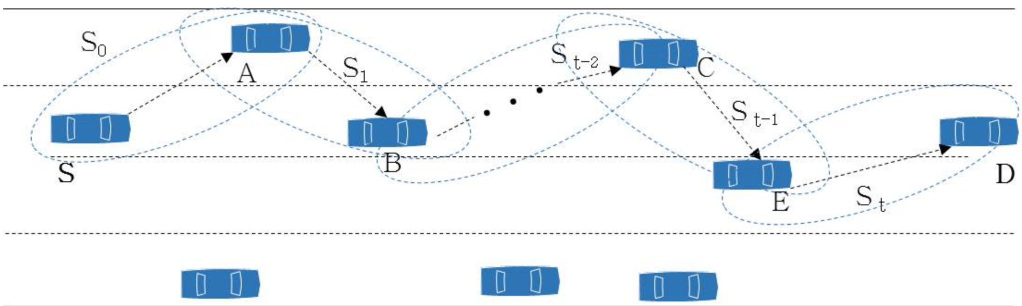


Fig. 1. Communication connectivity in VANETs

In the proposed algorithm, the power can be dynamically changed to maximize the payoff. Because the payoff of the transmitter is a measure of the individual quality of the selected power, its formulation strongly depends on the network feedback [13]. As a transmitter, the vehicle *i*'s payoff with message *m* and *k*th power level ($\Re_i^k(m)$) is defined as follows.

$$\Re_i^k(m) = \left(\gamma \times (1 - \frac{p_k}{p_{MAX}})\right) + \frac{1}{1 + |\mathcal{N}_i|} \times \left(\beta \times \sum_{x \in \mathcal{N}_i} \text{Feedback}_x^k(m)\right) \quad (1)$$
$$\text{s.t., Feedback}_x^k(m) = \mathbf{1}_{\{\Gamma_x \geq \Gamma^{tar}\}} \text{ or } \mathbf{0}_{\{\Gamma_x < \Gamma^{tar}\}}$$

where γ and β are parameters to tune the interest we have in satisfying the power consumption and the network feedback, respectively. $p_k \in \boldsymbol{\mathcal{P}}$ is the selected power level among a finite possible power set $\boldsymbol{\mathcal{P}} = \{p_1, .. p_k .., p_{MAX}\}$ where p_{MAX} is the maximum power level. $\mathcal{N}_i$ is the set of vehicles in the vehicle i's *CR* and the $\text{Feedback}_x^k(m)$ is a one bit value, which depends on the nature of the feedback chosen in the VANET. $\mathbf{\Gamma}_x$ is the *SINR* of $x \in \mathcal{N}_i$ and $\mathbf{\Gamma}^{tar}$ is the target *SINR* for wireless communications. For each message (m) packet transmission, the outcome of $\text{Feedback}(m)$ is obtained, periodically.

Usually, there is a trade-off between the feedback frequency and the control overhead in the interactive feedback mechanism. Therefore, the feedback frequency is chosen based on desired system performance objectives. If the frequency is relatively low (which enables the algorithm to react more quickly and accurately to the changing network situation), system performance is more nearly optimal at the expense of control overhead. For large values of frequency, the control overhead is less but at the expense of system inefficiency; it could be too slow in adapting to real traffic changes. By considering this tradeoff, we decide the feedback frequency as each packet transmission. The According to (1), the payoff is decided to be monotonically decreasing with the power consumption while increasing with the number of successful transmission feedback.

Owing to the highly dynamic VANET environment, we are unable to determine the optimal power level accurately. To adaptively set the power level, we should be responsive to the current network information. The proposed algorithm estimates the payoff of the selected power level based on the payoff history and recent payoff changes. As a weighted average of two quantities, the accumulated payoff of k^{th} power level ($EP_t[k]$) is modified as follows.

$$\begin{cases} EP_{t+1}[k] = (1-\alpha) \times EP_t[k] + \alpha \times \Re_i^k(m) \\ EP_{t+1}[j] = EP_t[j], \quad \text{s.t. } j \neq k \end{cases} \tag{2}$$

where $EP_{t+1}[k]$ is the accumulated payoff of k^{th} power level for the next interval. Therefore, $EP[\cdot]$ is recursively updated during operation rounds. The parameter α controls the relative weights given to recent and past estimation histories in our decision. Under dynamic VANET environments, a fixed value of α cannot effectively adapt to the changing network conditions. Therefore, each vehicle dynamically modifies α at the end of each operation round to make it more responsive to the current VANET conditions. When the difference between $\Re_i^k(m)$ and $EP_t[k]$ is small, the value of α makes little difference on VANET performance. But under dynamic network changing situation, the value of α can affect the performance significantly. If the traffic is uniformly distributed over the entire VANETs and mobility is relatively uniform, we can put more emphasis on the payoff history, i.e., on $EP_t[k]$. In this case, a lower value of α is more suitable. But if traffic distributions and mobility is non-uniform, due to temporal and spatial traffic fluctuations, the payoff estimation should strongly depend on the recent payoff, i.e., on $\Re_i^k(m)$. In this case, a higher value of α is more suitable. Therefore, we must decide on the value of α by considering the current VANET traffic conditions and by treating it as an on-line decision problem. In the proposed algorithm, α is dynamically adjusted as follows.

$$\alpha = \frac{||\Re_i^k(m) - EP_t[k]||}{\mathbf{max}\,\{\Re_i^k(m),\ EP_t[k]\}} \tag{3}$$

To adaptively select the power level, we define the vector $\mathbf{V}[k]$ where $1 \leq k \leq |\boldsymbol{\mathcal{P}}|$. Based on $EP_t[\cdot]$ values, $\mathbf{V}[k] = 1$ where $k = \{\, k \mid \mathbf{max}_{1 \leq k \leq |\boldsymbol{\mathcal{P}}|} EP_t[k]\}$ and the remaining elements $\mathbf{V}[l]_{\,1 \leq l \leq |\boldsymbol{\mathcal{P}}|, l \neq k}$ equal to 0. For the $(t+1)^{\text{th}}$ operation round in the vehicle i, the selection probability ($\mathbb{Q}_i^k(t+1)$) of k^{th} power level (p_i^k) is defined as follows.

$$\mathbb{Q}_i^k(t+1) = \mathbb{Q}_i^k(t) + \frac{1}{t+1}(\mathbf{V}[k] - \mathbb{Q}_i^k(t)) \quad (4)$$

In order to implement the time driven approach for the equation (4) operations, we partition the time-axis into equal intervals of length *unit_time*, which is a time period for operation round. $\mathbb{Q}_i^k(\cdot)$ value is periodically modified every *unit_time*. Finally, the vehicle *i*'s power level (p_i) for the next round operation is stochastically given according to the distribution by $\mathbb{Q}_i(\cdot)$. Therefore, based on the interactive feedback mechanism, each vehicle adaptively decide its power level to maximize the payoff.

3.2 The Estimation Mechanism for Packet Forwarding Probability

In VANETs, one vehicle behavior positively or negatively affects another vehicle's behavior, depending on whether there was a choice of forwarding the message or not. It is called interdependency. Under the interdependent situation, strategic actions are necessary. According to the strategic interaction theory, called the game theory, a vehicle can choose the best strategy to respond to an expected behavior from the other vehicles involved [14].

The game theory may coordinate the vehicle communication in a distributed control manner; it can describe the possibility to react to the actions of the other vehicles and analyze the situations of conflict and cooperation. Usually, the formal game model consists of players, the possible strategies of the players, and utility functions of the strategies [15]. Therefore, to represent a traditional game *G*, the game model components are given by *G* = < *Players* ($\mathbb{N}$), *Strategies* ($\mathbb{S}$), *Utility_functions* ($\mathbb{U}$) >, where $\mathbb{N}$ is a finite set of players $\{1,2,\ldots n\}$, $\mathbb{S}$ is a non-empty set of the strategies, i.e., $\mathbb{S} = \{S_1,\ldots, S_n\}$, and $\mathbb{U}$ is the utility function set ($\{u_1,\ldots, u_n\}$) of players. Each player's satisfaction level can be translated into a quantifiable metric through a utility function. Therefore, a utility function is a measure of the satisfaction experienced by a player; it is a result of a selected strategy. Usually, the utility function maps the user-level satisfaction to a real number, which represents the resulting payoff. The goal of each player is to maximize his own payoff by selecting a specific strategy where $\mathbf{max}_{S_i}: u_i\,(S_i) \rightarrow \mathfrak{R}$, $S_i \in \mathbb{S}$ and $i \in \mathbb{N}$ [15].

To formulate the packet broadcast mechanism as a game model, the vehicle *i*'s strategy S_i represents $S_i = \{f, d\}$, where $S_i = f$ implies a message forwarding and $S_i = d$ implies a message dropping. The vehicle i that forwards a message will have utility. By taking into account the cost and the payoff of message propagation, it is calculated as $\mathfrak{R}_i^k(m) - \mathcal{C}_i^k(m)$ where $\mathfrak{R}_i^k(m)$ is the payoff of message forwarding and $\mathcal{C}_i^k(m)$ is the forwarding cost. According to (1), $\mathfrak{R}_i^k(m)$ is obtained. $\mathcal{C}_i^k(m)$ is defined by considering the cost/payoff relation to forward the message. In general, the cost function should be non-negative and convex in order to allow existence of at least one non-negative minimum. In order to achieve this goal, it is sufficient to formulate the deviation from target *SINR* as a non-negative and convex function [16]. In addition, it should be assumed that $\mathfrak{R}_i^k(m) > \mathcal{C}_i^k(m)$ to prevent no vehicle from participating the message forwarding. Finally, the vehicle *i*'s cost function ($\mathcal{C}_i^k(m)$) with the message *m* is given by.

$$\mathcal{C}_i^k(m) = \ \mathbf{min}\,\{\mathfrak{R}_i^k(m), [\,\gamma \times \frac{p_k}{p_{MAX}} + \varepsilon\ \times cosh(\mathbf{\Gamma}_i - \mathbf{\Gamma}^{tar})]\} \quad (5)$$

where γ and ε are control parameters for the cost evaluation. They can be adjusted to put more emphasis on power level or *SINR* deviation. γ is the same parameter used in the equation (1). If the value of ε is increased, achieving target *SINR* ($\boldsymbol{\Gamma}^{tar}$) is more emphasized, otherwise power consumption is prioritized.

In multi-hop communications, the broadcast mechanism causes excessive redundant packet forwarding on the VANET and the message could be lost due to collisions. This is known as the *broadcast storm* problem; it might result in higher network overhead and delay for emergency messages [14]. Therefore, how many vehicles should forward a broadcast message is an important criterion. In reality, all the vehicles in VANETs are self-organized and responsible for tackling this problem in a distributed coordinated manner. To mitigate the *broadcast storm* problem, we formulate the message forwarding mechanism as a broadcasting game model. This game is played whenever a vehicle receives a broadcast message.

Among vehicles that receive the message in a *CR*, a cost ($\mathcal{C}(m)$) is associated to the message forwarding vehicle. Because of that cost, some vehicles in the same *CR* expect that at least one vehicle forwards the message at the cost and they can only benefit by not doing so. However, if no one vehicle forwards the message within the *CR*, the worst possible outcome is obtained for all vehicles. Based on this assumption, we can develop the utility function for each vehicle. Let $P_F(i)$ be the probability of message being forwarded by the vehicle *i* and $P_{N\_F}(i)$ be the probability of message not being forwarded by the vehicle *i*, where $P_F(i)$ + $P_{N\_F}(i)$ = 1. According to $P_F(i)$ and $P_{N\_F}(i)$, the vehicle *i*'s utilities with message forwarding ($U_F(i)$) and with non message forwarding ($U_{N\_F}(i)$) are defined as follows.

$$\begin{cases} U_F(i) \; = \; (1 - P_{N\_F}(i)\,) \times (\mathfrak{R}_i^k(m) - \mathcal{C}_i^k(m)) \\ U_{N\_F}(i) = \; P_{N\_F}(i) \times \left(1 - \prod_{j=1, j\neq i}^{\mathcal{N}_i} P_{N\_F}(j)\right) \times \mathfrak{R}_i^k(m) \end{cases} \tag{6}$$

Based on (6), the total utility of vehicle *i* ($U_T(i)$) is defined as follows.

$$\begin{aligned} U_T(i) = & \left((1 - P_{N\_F}(i)\,) \times (\mathfrak{R}_i^k(m) - \mathcal{C}_i^k(m))\right) \\ & + \left(P_{N\_F}(i) \times (1 - \prod_{j=1, j\neq i}^{\mathcal{N}_i} P_{N\_F}(j)\,) \times \mathfrak{R}_i^k(m)\right) \end{aligned} \tag{7}$$

To maximize $U_T(i)$, the best $P_F(i)$ and $P_{N\_F}(i)$ values are obtained by differentiating the $U_T(i)$ function with respect to $P_{N\_F}(i)$ and equating it with zero.

$$\begin{aligned} \frac{\partial U_T(i)}{\partial P_{N\_F}(i)} & = \left(1 - \prod_{j=1, j\neq i}^{\mathcal{N}_i} P_{N\_F}(j)\right) \times \mathfrak{R}_i^k(m) - \mathfrak{R}_i^k(m) + \mathcal{C}_i^k(m) \\ & = q^{\mathcal{N}_i - 1} \times \mathfrak{R}_i^k(m) - \mathcal{C}_i^k(m) = 0 \end{aligned} \tag{8}$$

Finally, we can obtain $P_{N\_F}(i) = \left(\frac{\mathcal{C}_i^k(m)}{\mathfrak{R}_i^k(m)}\right)^{\frac{1}{\mathcal{N}_i - 1}}$ and $P_F(i) = 1 - P_{N\_F}(i) = 1 - \left(\frac{\mathcal{C}_i^k(m)}{\mathfrak{R}_i^k(m)}\right)^{\frac{1}{\mathcal{N}_i - 1}}$. Based on the symmetric mixed strategy with probability $P_F(i)$, each vehicle may forward a message; Diekmann proved that this kind of game goes into Nash equilibrium [17].

3.3 Packet Rate Control Algorithm for VANETs

IEEE 802.11e is an approved amendment to the IEEE 802.11 standard that defines a set of QoS enhancements for wireless communications through the MAC layer. The MAC layer is responsible for optimal fair channel assignment while preventing collisions that occur if two or more network nodes send frames simultaneously [8]. Carrier Sense Multiple Access (CSMA) is a well-known MAC protocol for carrier transmission access. In this protocol, any node can try to send a frame at any time. Therefore, a collision is possible. To avoid a simultaneous access to the channel, the CSMA protocol adopts a backoff algorithm based on a Contention Window (*CW*). In the backoff algorithm, each node waits for a random time, limited to its *CW* before transmission, and retries until successful in getting its transmission sent [5].

Initially, the *CW* size is assigned the minimum *CW* value (CW_{min}) and the backoff process is started independently in every node; a node computes a random value called backoff time, in the range of 0 and *CW* size. Actually, when the network load increases, the backoff time should be increased to minimize the collision probability. Therefore, after each unsuccessful transmission, *CW* is multiplied by σ, which is called the persistence coefficient; σ multiplication decreases the collision probability through the *CW*'s increase. For each collision, the *CW* size increases up to its maximum value $CW_{max} = \sigma^n \times CW_{min}$ where *n* is the number of subsequent retransmission. Since *CW* is increased till reaching the CW_{max}, this backoff time will be preserved until the packet is transmitted successfully. After successful transmission, the *CW* will be set back to CW_{min} [5].

During real world VANET operations, each message competes with other messages to gain a transmission opportunity. However, emergency messages especially require limited end-to-end delay and a low packet loss rate; they should be processed preferentially. The *CW* size control approach can be an effective method to prioritize one message over the other messages. By shortening the *CW* size, some messages can have a higher probability of being transmitted with low latency. In this paper, we choose σ as a QoS parameter. When a message is admitted, it will be attached with σ. However, different messages require different QoS. Therefore, the σ value is different for each message. In the proposed scheme, messages are categorized into four priority classes: *class I* (delay-critical emergency messages), *class II* (accident-related messages), *class III* (warning messages) and *class IV* (general messages). According to the required QoS in the vehicle *i*, σ value for the message *m* is assigned as follow:

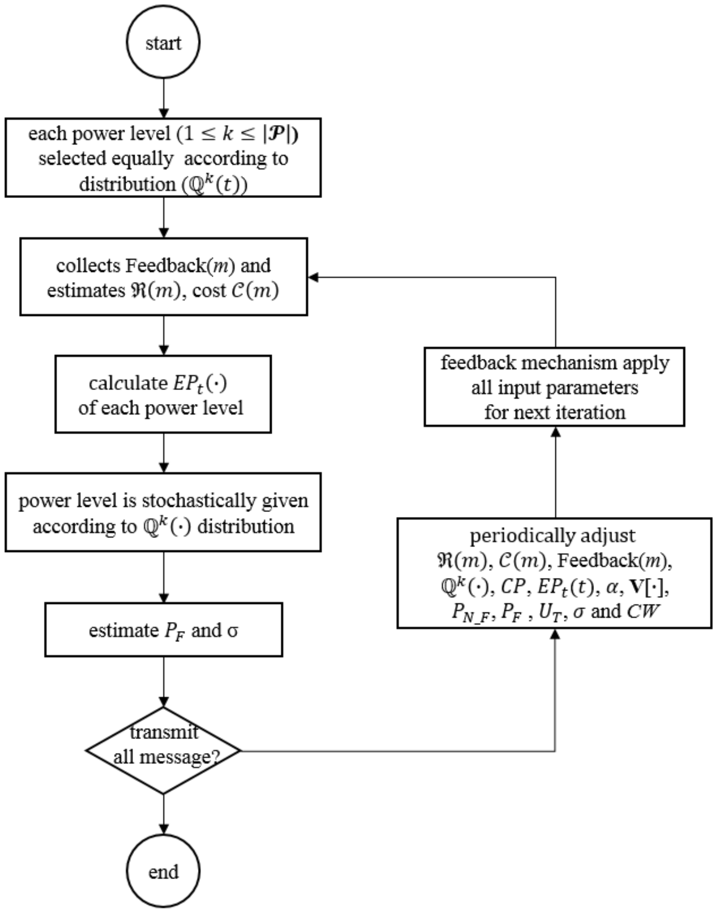
$$\sigma_i(m) = \begin{cases} (\xi_I + [1 - P_F(i)])^{\xi_I}, & \text{if } m \in class\ I \\ (\xi_{II} + [1 - P_F(i)])^{\xi_{II}}, & \text{if } m \in class\ II \\ (\xi_{III} + [1 - P_F(i)])^{\xi_{III}}, & \text{if } m \in class\ III \\ (\xi_{IV} + [1 - P_F(i)])^{\xi_{IV}}, & \text{if } m \text{ t} \in class\ IV \end{cases} \quad \text{s.t.}, P_F(i) = 1 - \left(\frac{\mathcal{C}_i^k(m)}{\Re_i^k(m)}\right)^{\frac{1}{\mathcal{N}_i - 1}} \qquad (9)$$

where ξ_I, ξ_{II}, ξ_{III} and ξ_{IV} are persistence coefficients for each type messages. By modifying the σ parameter based on (9), each vehicle is able to adjust the backoff interval through *CW*. Therefore, the proposed scheme can effectively support the message differentiation according to the required QoS.

3.4 The main steps of the proposed scheme

In this work, the goal is to design a totally distributed, low-complexity scheme for wireless communications in VANETs. Generally, the research on VANETs has been focusing on either transmission power control or packet rate control as means to prevent the *broadcast storm* problem. To overcome the limitations of power-only and rate-only approaches, we combine both power and packet rate control mechanisms through the dynamic adaptation of transmission power along with that of the *CW*. By using the advantages of both mechanisms, our integrated approach results in the high VANET throughput and better QoS differentiation.

In order to make reliable connections and mitigate adverse effects due to the fixed power and rate mechanisms, the proposed scheme uses a cross layer approach to dynamically adapt the transmission power (in PHY-layer) and *CW* size (in MAC-layer). Based on the current VANET situation, the power level of each vehicle is adaptively adjusted and the prioritization of messages is performed according to their urgency. The flowchart of the proposed control algorithm can be described as follows.



Flowchart 1. The proposed VANET control algorithm

4. Performance Evaluation

In this section, we evaluate the performance of the proposed scheme using a simulation model; a simulation analysis allows a complex realistic modeling. With a simulation study, we compare the performance of our scheme with other existing schemes [5, 12] and can confirm the superior performance of the proposed approach. To ensure the model is sufficiently generic to be valid in a real-world, the assumptions implemented in our simulation model were as follows.

- The simulated system is assumed as a CSMA system for VANET.
- 100-nodes are distributed randomly over the 10 km road area and the velocity of each mobile vehicle is randomly selected from [30, 40, 50] m/s.
- The process for new message transmission is Poisson with rate λ (messages/s), and the range of offered traffic load was varied from 0 to 5.0. Based on this assumption, *unit_time* in our simulation model is one second.
- The capacity of network bandwidth is 30Mbps, and each message consists of CBR packets.
- Network performance measures obtained on the basis of 50 simulation runs are plotted as a function of the offered traffic load.
- The size of messages is exponentially distributed with different means for different message applications.
- For each message (m) packet transmission, the outcome of Feedback(m) is obtained, periodically.
- For simplicity, we assume the absence of physical obstacles in the experiments.

Table 1 shows the system parameters used in the simulation. In order to emulate a real network system and for a fair comparison, we used the system parameters for a realistic simulation model [5, 12, 15].

Table 1. System parameters used in the simulation experiments

Traffic Class	Message Application	Bandwidth Requirement	Connection Duration Average /sec
I	delay-critical emergency messages	32 Kbps	30 sec (0.5 min)
II	accident-related messages	32 Kbps	120 sec (2 min)
		64 Kbps	180 sec (3 min)
III	warning messages	128 Kbps	120 sec (2 min)
		256 Kbps	180 sec (3 min)
IV	general messages	384 Kbps	300 sec (5 min)
		512 Kbps	120 sec (2 min)

Parameter	**Value**	**Description**
γ	5	control parameter to emphasize the power consumption
β	1.5	control parameter to emphasize the feedback
unit_time	1 second	a time period for operation round
p_{min}, p_{max}	$50mW$, $100mW$	pre-defined minimum and maximum power levels
p_i	$p_{min} \leq p_i \leq p_{max}$	power levels for the vehicle *i* (50,60,70,80,90,*100mW*)
ε	5	control parameter to emphasize the *SINR*
CW_{min}	1	The size of minimum contention window
CW_{max}	10	The size of maximum contention window
ξ_I	1	persistence coefficients for *class I* message
ξ_{II}	1.2	persistence coefficients for *class II* message
ξ_{III}	1.4	persistence coefficients for *class III* message
ξ_{IV}	1.6	persistence coefficients for *class IV* message

Parameter	**Initial**	**Description**	**Values**
α	1	decision parameter for $EP[\cdot]$ estimation	0 or 1

Performance measures obtained through simulation are *Success Transmission Probability* (*STP*) for *Class I* messages, normalized packet delay, network throughput and *Service Fail Ratio* (*SFR*) for emergency messages, etc. In this paper, we compare the performance of the proposed scheme with existing schemes – the *PCJA* scheme [5] and the *JPRC* scheme [12]. For a fair comparison, we assume that each vehicle in all the schemes has same behavior, and the communication procedure is operated, simultaneously. The *PCJA* and the *JPRC* schemes are also developed as VANET management algorithms that capture the notion of power and rate control mechanisms. However, even though these existing schemes [5, 12] effectively control the VANETs, there are several disadvantages. First, these existing schemes rely on impractical assumptions for real operations. Control algorithms based on inapplicable assumptions can potentially cause erroneous decisions. Second, these schemes cannot dynamically estimate the current network conditions. Therefore, each vehicle is unaware of effective ways to reach a destination, which can lead to suboptimal decisions. Third, these schemes operate the VANET system by some fixed system parameters. Under dynamic network environments, it is an inappropriate approach to operate real world network systems. In addition, they cause extra control overhead with the high complexity. The increased overhead can exhaust the network resources and require intractable computation.

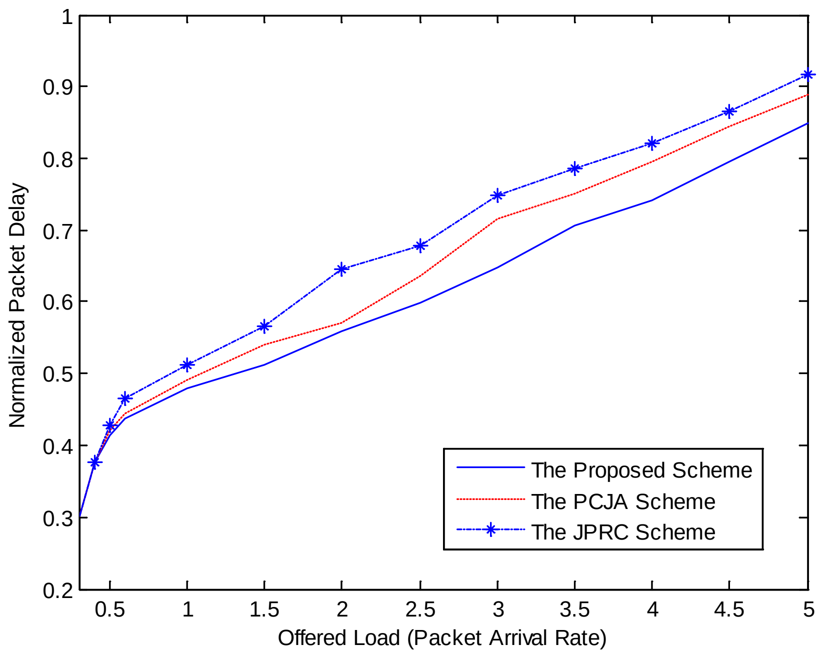


Fig. 2. Normalized Packet Delay

Fig. 2 compares the performance of each scheme in terms of the normalized packet delay, which is one target QoS. It can be interpreted as normalized end-to-end packet delays. As the traffic load increases, large amounts of packet exchanges inevitably cause communication congestion. Therefore, the packet delay increases. All the schemes have similar trends. However, the proposed scheme constantly monitors the current network conditions and responds effectively for adaptive management. Therefore, the proposed algorithms can have better packet delay than other schemes from low to heavy traffic load intensities.

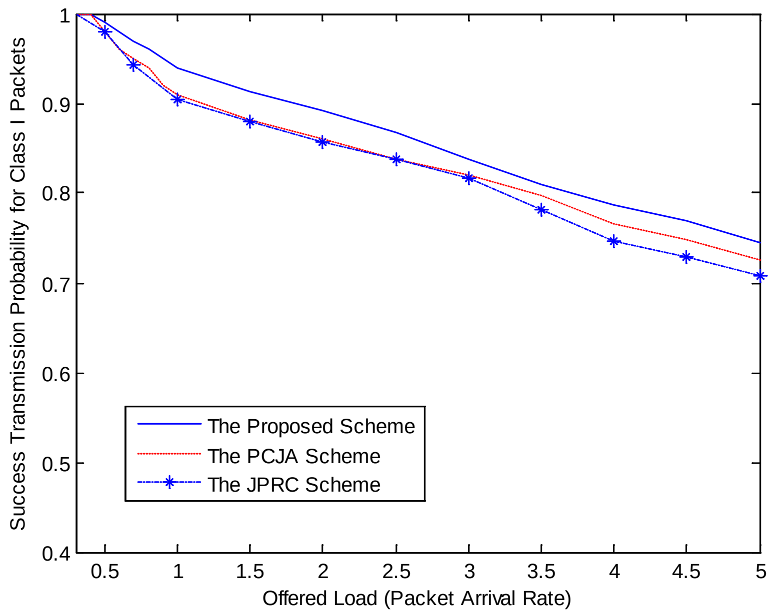


Fig. 3. *STP* for *Class I* packets

In **Fig. 3**, the comparison of the *Success Transmission Probability* (*STP*) for *Class I* packets is shown. In this work, the *STP* is defined as a probability of packet's successful transmission in a given time period. To obtain a higher probability of successful transmission, control decisions have to be made in real time. The proposed algorithm would employ online methodology to control VANETs. In addition, the low complexity of decision mechanisms makes the proposed scheme effective for real network operations. Therefore, the proposed scheme can provide a better QoS guarantee than other schemes.

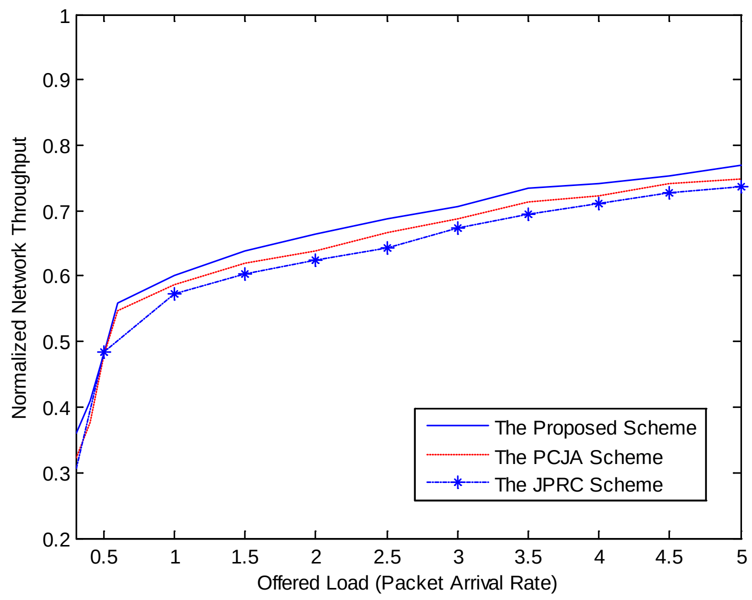


Fig. 4. Normalized Network Throughput

Fig. 4 shows the normalized network throughput. In network operations, network throughput is the rate of successful message delivery over a communication channel. This is usually measured in bits per time slot (e.g., bit/s or bps). Usually, throughput is essentially synonymous with digital bandwidth consumption. In this work, network throughput is normalized for the performance comparison. Because of the inclusion of the adaptive interactive online approach, the proposed scheme can adapt to the current VANET situation and this results in better throughput. This feature is a highly desirable property for real world VANET operations.

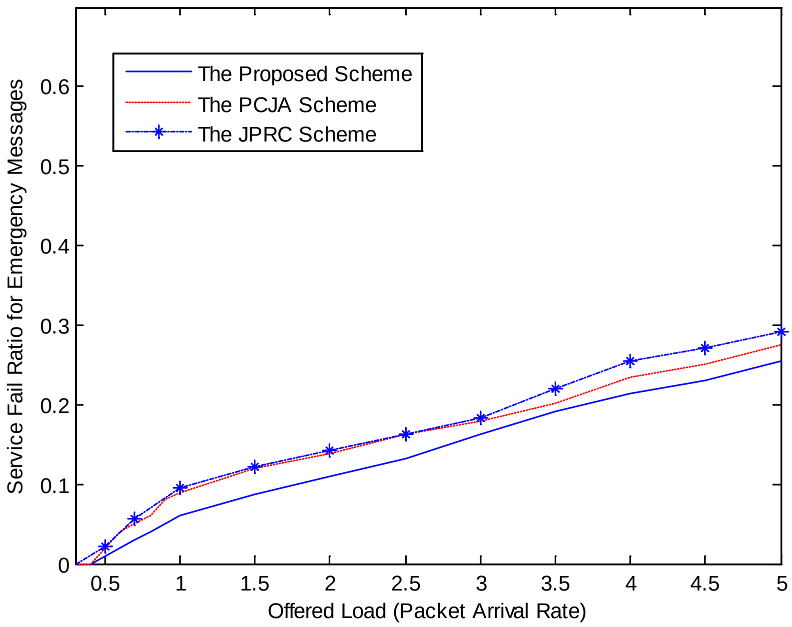


Fig. 5. *SFR* for emergency messages

The curves in **Fig. 5** present the *Service Fail Ratio* (*SFR*) for emergency messages under different network traffic load. When the traffic load is low (λ <0.3), the performance of all the schemes is identical. This is because all the schemes have enough network capacity to support the emergency message services. However, as the traffic congestion increases, the VANET system will run out of the capacity for emergency messages operations. Therefore, the *SFR* increases linearly with the network traffic load. Under various traffic load conditions, the proposed scheme exploits effectively to balance the system performance between contradictory requirements while achieving a lower *SFR* than other schemes.

The simulation results shown in **Figs. 2-5** demonstrate that the proposed scheme generally exhibits superior performance compared with the other existing schemes under widely different VANET traffic load situations. In order to reach peak network performance, our work is motivated by the fact that the fixed transmit power and QoS related parameters do not enhance the VANET performance. To achieve better performance, we develop the interactive feedback mechanism of joint transmission power and QoS parameters in a cross layer approach. Therefore, the proposed scheme constantly monitors the current VANET conditions and can adaptively balance appropriate network performance, while other schemes [5, 12] cannot offer such attractive network performance.

5. Summary and Conclusions

As a result of their promising features and potentially wide range of applications, VANETs and their communication properties have recently received a lot of attention in the research community. However, the broadcast over multi-hop VANETs poses many challenges due to link unreliability, hidden nodes, message redundancy, the *broadcast storm* problem, etc., which greatly degrade network performance. This paper investigates the VANET communication algorithms based on the dynamic joint adaptation of transmission power and packet rate. According to the online feedback mechanism, the proposed scheme adaptively interacts with the current VANET situation, and dynamically adjusts the power level and QoS parameters. Calculating the power level, rebroadcast probability and the *CW* size are the major contributions of our work. Simulation results show that the proposed scheme is successful in getting better throughput with lower average end-to-end delay than other existing schemes.

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