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Joint optimization and threshold structure dynamic programming with enhanced priority scheme for adaptive VANET MAC

Joanne Mun-Yee Lim[1,2] · **Yoong Choon Chang**[2] · **Mohamad Yusoff Alias**[2] · **Jonathan Loo**[3]

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Abstract Nodes in vehicular ad-hoc network (VANET) are highly mobile, traversing in unpredictable and varying environment. Therefore, contention window size and transmission power should adapt according to the high mobility transmission environment. In this paper, we propose an adaptive VANET medium access control (MAC) layer with joint optimization for VANET (MACVS) which aims at minimizing average delay and maximizing packet success rate. An adaptive joint optimization with proposed threshold structure dynamic programming, with closed loop feedback control system, is designed to optimize contention window size and transmission power. Adaptive optimization is done based on road traffic conditions and transmission reliable distance range (depicted by interference and noise), by monitoring the continuous change and threshold of received signal strength to interference and noise ratio. Mathematical expressions have been developed for the MACVS optimization framework, and the produced analytical results show good agreement with the simulation results. Simulations with different arrival rates and urban map of city center show that the proposed MACVS with low complexity joint optimization effectively reduces end-to-end delay while achieving high packet success rate under various network traffic condition.

Keywords Contention window · Optimization · MAC · Priority · Transmission power

Abbreviations

VANET	Vehicular adhoc network
MAC	Medium access control
SINR	Signal to noise and interference ratio
DP	Dynamic programming
TRDR	Transmission reliable distance range
MACVS	Adaptive VANET MAC with joint optimization
EDCA	Enhanced distributed channel access
MarPVS	Markov distance prediction with new priority VANET scheme
QoS	Quality of service
CW	Contention window size

✉ Joanne Mun-Yee Lim
jlmy555@gmail.com

Yoong Choon Chang
ycchang@mmu.edu.my

Mohamad Yusoff Alias
yusoff@mmu.edu.my

Jonathan Loo
J.Loo@mdx.ac.uk

[1] Faculty of Engineering, SEGi University, Jalan Teknologi, Kota Damansara, 47810 Petaling Jaya, Selangor, Malaysia

[2] Faculty of Engineering, Multimedia University, Persiaran Multimedia, 63100 Cyberjaya, Selangor, Malaysia

[3] School of Science and Technology, Middlesex University, London NW44BT, UK

1 Introduction

Vehicular ad-hoc network (VANET) provides safety and comfort applications for intelligent transportation system, with the aim of improving driving safety through wireless communication. VANET is governed by IEEE802.11p with Enhanced Distributed Channel Access (EDCA) priority scheme that defines four levels priority scheme solely based on data type. VANET nodes are highly mobile moving in unpredictable environments with obstacles such as buildings, mountains, cars, towers etc., which directly contributing to the degradation of Quality of Service (QoS) performance. However, VANET has strict requirements on the nodes performance specifically end-to-end delay. To ensure transmission efficiency in VANET, delay and interference should be kept at minimal as transmissions are affected by high mobility nodes. In order to minimize delay and interference, efficient packet scheduling and transmission power should be ensured. This can be done by having transmission priorities, transmission window size and transmission power, adapted to varying environment of VANET, where the road traffic conditions have direct effect to wireless network traffic conditions. While the aforementioned are important in VANET, the existing default IEEE802.11p scheme is not adaptive. The existing default IEEE802.11p defines constant contention window size and transmission power parameters regardless of traffics conditions and VANET environment.

In this paper, we investigate an adaptive VANET Medium Access Control (MAC) called MACVS, where the main novelty is its adaptability under various road traffics. In the proposed MACVS, SINR is used as an indicator to represent VANET packet transmission reliability. SINR measures signal strength with respect to the internal interference (interference within the overlap area such as collision) and external interference (interference outside the overlap area such as hidden terminal) and noise as a whole [1–4].

The contribution of the proposed MACVS lies on the adaptive MAC VANET based on optimization and closed loop feedback control system. In order to elaborate on the optimization mechanism of the proposed MACVS, interference which is the optimization factor of MACVS in VANET is explained.

Ideally, a high SINR is desired for efficient packet transmission. However, an increased interference will result in reduction of SINR. Increased interference can be caused by high volume road traffics which lead to high volume of packet transmission and low SINR. On the other hand, a low SINR is caused by high interference due to high number of overlapping transmission regions as shown in Fig. 1a. In case of less congested road, the overlapping transmission would most likely be rather sparse and localized as shown in Fig. 1b, in that, SINR would be lower [5–8].

Due to varying nature of VANET environment, interference varies and fluctuates [9–13]. To ensure successful and reliable transmission, SINR is a variable which can be used to measure transmission reliability as it measures a ratio of transmission power (signal strength) with respect to interference and noise.

With a road traffic and transmission reliability indicator, SINR, the VANET MAC parameters (contention window size and transmission power) can be optimized according to network conditions. The optimal control of VANET MAC parameters, transmission power (which affects the coverage range, adjacent interference, signal strength and transmission reliability) and contention window size (which affects the packet end to end delay) can be achieved to ensure efficient VANET packet scheduling. To jointly optimize transmission power and contention window size, a DP structure is applied. However, in order to minimize the complexity of DP, we have implemented a threshold structure DP in MACVS. To further improve packet scheduling, a priority level scheduling based on TRDR and data type has also been implemented in MACVS. In addition, to ensure proper control of optimization process, a closed loop feedback control system has been applied to MACVS.

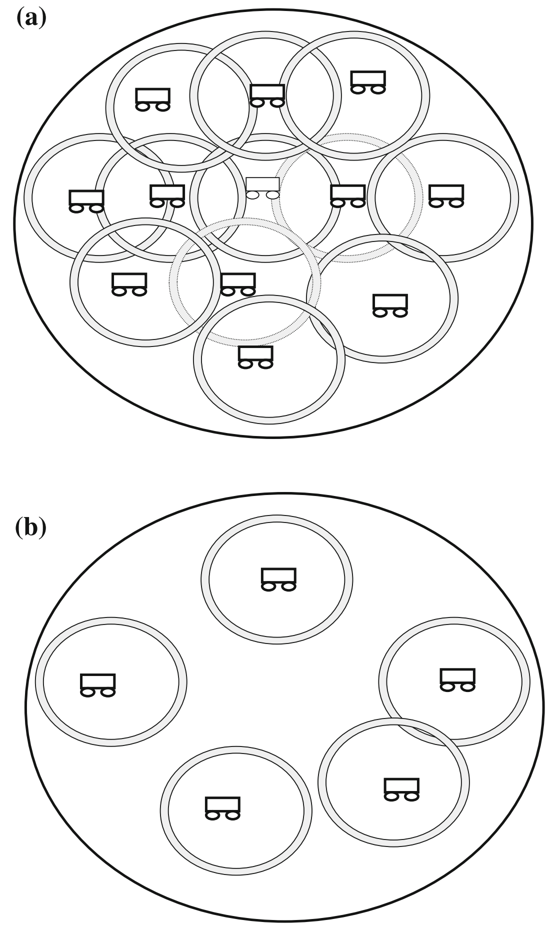


Fig. 1 **a** Interference in Congested Traffic. **b** Interference in Congestion Free Traffic

The main contributions of this work are as follows: Firstly, we adopt the usage of change of SINR and threshold SINR as indicators for VANET environments and traffic conditions [1–3] where the change of SINR is used to monitor the change of transmission environment, whereas the threshold SINR is used to measure the current transmission environment. Secondly we optimized the transmission power and contention window size with the use of the proposed threshold DP structure and closed loop feedback control system. Thirdly, we jointly implemented five priority levels based on transmission reliability measured based on SINR, TRDR and data type, Markov Distance Prediction with New Priority VANET Scheme (MarPVS) with MACVS. Fourthly, we derived the mathematical expressions for optimized weightings, internal and external interferences and finally the results are used to derive the average delay experience by each node.

The aforementioned points are the efforts for adaptive MAC with joint optimization on contention window size and transmission power for VANET TRDR based priority scheme (MACVS) that aims at minimizing the average delay and maximizing packet success rate. With low complexity joint optimization and adaptability of MACVS tested with different arrival rates under the urban map of city center simulation platform, we show that MACVS has efficient adaptability under various VANET conditions by achieving minimum end-to-end delay and maximum packet success rate.

The rest of the paper is organized as follows. Section 2 illustrates the existing work. Section 3 discusses the proposed MACVS. Section 4 presents and discusses the simulation, analytical parameters and results. Section 5 concludes the paper.

2 Related work

IEEE802.11p defines the standard that governs VANET communication system. For cooperative vehicle safety applications, VANET MAC EDCA has specific priority scheme to allow transmission to be classified into different categories. However, the current VANET MAC EDCA defines constant priority scheme, constant transmission power and contention window size that do not address high mobility issues.

Due to high mobility and varying nature in VANET, transmission degradation can be caused by different sources. One of the main reasons for transmission degradation is interference. Path loss modeling specifically for VANET is defined in [1] where interference is one of the main expressions. With strict messaging frequency, collision becomes inevitable. It is found that interference is one of the causes of collision. Various ways are used to reduce packet collision. One of the methods discusses using an application-level control of the message transmission phase for collision control [2]. A collision alleviation scheme is also introduced for IEEE802.11p VANET to minimized packet collision [3].

From the aforementioned literature reviews, packet collision is shown to be one of the common reasons for transmission degradation in VANET. Packet collision detection is one of the common methods specified to represent traffic conditions [4, 15]. Since interference is observed to be root cause of transmission degradation which includes packet collision [15–17], detecting interference allows the detection of packet collision [18–22].

Nodes in VANET have high mobility and moves from different transmission range to another abruptly which makes the VANET nodes prone to latency, security issues and transmission failure [23–29]. Therefore, to overcome high mobility, varying environment and interference in VANET [30–34], a measurement parameter that caters for all types of degradation is important for performance optimization [1, 15, 16].

In our proposed work, continuous observations on two parameters namely, change of SINR and received SINR, are used to determine the VANET transmission reliability and traffic conditions. SINR can only be used to detect transmission degradation, and not to solve packet dropped issues. Once transmission degradation is detected, the optimization of two parameters namely, contention window size and transmission power, can be achieved to ensure successful packet transmission.

IEEE802.11p defines a four levels priority scheme, with priority set based on contention window size called the EDCA, regardless of traffic transmission condition [35]. Nature of VANET is inherently dynamic with varying nature and highly mobile nodes. Thus, transmission reliability (measured by distance, interference and noise), TRDR is used in determining transmission reliability consecutively. It is known that the transmissions between nodes in near distance (usually with high SINR) have higher success rate and shorter delay [36]. With the MACVS calculated TRDR, transmissions can be scheduled with priority classified based on TRDR and data type.

To address efficient scheduling in VANET, a priority scheme with five levels priority based on TRDR and data type [37] as defined in MarPVS [38] is implemented in the proposed MACVS. An additional priority level from the existing VANET IEEE802.11p EDCA is included for emergency messages to ensure emergency messages get transmitted on time which answers the main purpose of VANET which aims to reduce accidents by giving early warnings to drivers.

Due to VANET high mobility and varying nature, static parameters defined in IEEE802.11p standard should be made adaptive to ensure transmission performance. Therefore, optimization is important to ensure adaptability and optimal transmission performance in varying VANET environments. Optimization is a continuous nonlinear multi-objective concept. The idea of optimization is common specifically in random scenarios where optimal solution is scarce [14, 15]. In the proposed MACVS, a multi-objective optimization problem is divided into a set of sub problems and optimized to compute the best solution. To reduce computational limitations, a low complexity with heuristic suboptimal control which strikes a balance between adequate performance and convention DP approach is proposed. To the best of our knowledge, a threshold DP structure with multi-objective optimization has not been proposed in VANET MAC applications.

While the aforementioned literature laid a solid foundation in VANET, a multi-objective threshold structure DP optimization on contention window size and transmission power with enhanced priority scheme is important to ensure adaptability in VANET. Therefore, in the proposed MACVS, we divide the multi-objective problem into sub problems and present the detailed analytical modeling in five levels of priority, MarPVS and simulated the proposed MACVS with an urban map of Kuala Lumpur, Malaysia. Simulation results of MACVS are evaluated in comparison with the default IEEE802.11p scheme and an existing scheme in [4]. The proposed MACVS with optimization and adaptability presents minimum end-to-end delay and maximum packet success rate under various network traffics. The mathematical model and detailed analysis on MACVS is presented in the following sections.

3 The proposed adaptive VANET MAC MarPVS priority scheme with joint optimization on contention window size and transmission power (MACVS)

IEEE802.11p defines constant contention window size and transmission power for VANET MAC. Due to high mobility and varying nature of VANET, joint contention window size and transmission power based on traffic conditions (depicted by change and threshold of SINR) is proposed in this section to ensure adaptability. By applying principles of threshold DP structure, joint optimization and closed loop feedback control system [39, 40], on contention window size and transmission power, with MarPVS priority scheme [37, 38], we introduce MACVS with the objective of minimizing end-to-end delay and increasing packet success rate.

3.1 MACVS overall model

IEEE802.11p defines constant transmission power and contention window size where priorities are assigned based on EDCA scheme, which relies solely on data type. Priority is defined by transmission opportunity controlled by contention window size. Strictly speaking, VANET nodes are highly mobile and thus, contention window size and transmission power should be adaptively adjusted based on traffic conditions and VANET environment to minimize delay and maximize packet success rate.

To minimize the optimal end-to-end delay and increase packet success rate, we propose the joint optimization of contention window size and transmission power, MACVS as shown in Fig. 2. The objective of MACVS is to find the optimal contention window size and transmission power which minimizes the overall end-to-end delay. SINR is a parameter used to evaluate transmission reliability in a dynamic environment such as VANET [1, 15, 16]. Therefore, we introduce change of SINR (to evaluate transmission reliability over a period of time) and received SINR (to evaluate transmission reliability at that instant), to allocate weightings of contention window size and transmission power for different VANET environments and traffic conditions.

By applying the principle of DP, the problem (denoted as overall end-to-end delay), is decomposed into a sequence of sub problems (denoted as average sum of activity and interference regions). These sub problems are optimized with the objective of finding the best optimal weightings for contention window size and transmission power. DP requires an exhaustive search over all possible solutions which make it time consuming and energy inefficient. To overcome this problem, we propose a low complexity DP implementation which has a threshold structure related to SINR.

3.2 MACVS mathematical model and algorithm

In MACVS, we define an optimization methodology to optimize VANET performance specifically in the MAC layer. VANET MAC layer uses MACVS with DP to dynamically find the optimum solution. Since nodes in VANET are prone to unpredictable environments and ever changing network topologies, the optimum contention window size and transmission power, for different data types and TRDR, may fluctuate abruptly.

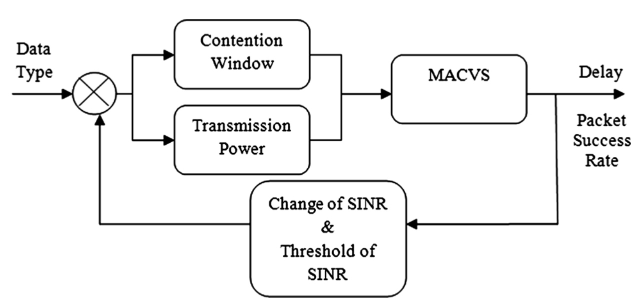


Fig. 2 MACVS Block Diagram

In order to cater for the unpredictable environment that vehicles in VANET often encounter, the nodes in VANET MACVS perform a joint optimization to find the optimum transmission power and contention window size, in order to achieve the lowest delay with highest packet success rate, under different VANET environments. In this section, the mathematical model with five MarPVS priority levels and the application of the proposed DP for MACVS is defined. The mathematical model presented is derived with the basic understanding in reference papers [37, 41].

3.2.1 The proposed MACVS joint optimization

TRDR prediction using Markov model in MarPVS [37, 38] is determined by the probability of near occurrence (P_{N_j}) derived based on (1) and the probability of far occurrence (P_{F_j}) derived based on (2).

T_{N_j} represents the total number of near occurrences within the jth interval, T_{F_j} represents the total number of far occurrences within the jth interval, and S_{Sj} represents the total sum of near and far occurrences.

$$\text{Probability of near occurence}, P_{N_j} = \frac{T_{N_j}}{S_{Sj}} \quad \text{where } j > 0 \tag{1}$$

$$\text{Probabilityof far occurence}, P_{F_j} = \frac{T_{Fj}}{S_{S_j}} \quad \text{where } j > 0 \tag{2}$$

Based on Markov Model, the probabilities of transitions between near distance to far distance are defined below. The probability of near-far transition (P_{NF_i}), the probability of far–far transition (P_{FF_i}), the probability of far-near transition (P_{FN_i}) and the probability of near–near transition (P_{NN_i}) are derived as in (3)–(6). T_{NF_i} represents the total number of near-far transition in the interval of *ith* times. On the other hand, T_{FNi} represents the total number of far-near transition in the interval of *ith* times. The transitions between near and far give an insight of the VANET car movements.

With the known transitions, future movement of car can be predicted with the use of Markov Model. Using S_{N_i} which represents the total number of near occurrences and S_{F_i} which represents the total number of far occurrences in the interval of ith times, we can predict the probability of VANET node future transition. The overall probability of TRDR prediction is derived based on (7) and (8). Based on the overall probabilities, the next location of VANET node can be predicted. FP_{Near} is compared with FP_{Far} where the higher probability indicates the next predicted range of transmission distance range reliability between communicating vehicles.

$$\text{Probability of near-far transition}, P_{NF_i} = \frac{T_{NFi}}{S_{N_i}} \quad \text{where } i > 0 \tag{3}$$

$$\text{Probability of far-far transition}, P_{FF_i} = 1 - \frac{T_{NF_i}}{S_{N_i}} \quad \text{where } i > 0 \tag{4}$$

$$\text{Probability of far-near transition}, P_{FN_i} = \frac{T_{FN_i}}{S_{F_i}} \quad \text{where } i > 0 \tag{5}$$

$$\text{Probability of near-near transition}, P_{NN_i} = 1 - \frac{T_{FN_i}}{S_{F_i}} \quad \text{where } i > 0 \tag{6}$$

$$\text{Overall probability of near occurence}, FP_{Near} = \left(P_{N_j} * P_{NN_i}\right) + \left(P_{F_j} * P_{FN_i}\right) \tag{7}$$

$$\text{Overall probability of far occurence}, FP_{Far} = \left(P_{N_j} * P_{NF_i}\right) + \left(P_{F_j} * P_{FF_i}\right) \tag{8}$$

IEEE802.11p adopts the EDCA with static priorities assigned according to data type for packet transmission. To ensure adaptability, a new priority level scheme is proposed [38] where MarPVS is adopted based on EDCA to assign priority based on TRDR and data type. The priority levels of MarPVS are defined in Tables 1 and 2.

Based on MarPVS priority levels defined in Tables 1 and 2, φ_ρ can be derived by dividing a constant period of time, defined by the maximum transmission time for the

Table 1 MarPVS priority scheme

Priority levels	Description	MarPVS traffic type (Designation)	MarPVS minimum contention window (CWmin)	MarPVS maximum contention window (CWmax)
5	Highest priority level (Lowest contention window)	*AC_SP*	*(aCWmin + 1)/8-1*	*(aCWmin + 1)/4 − 1*
4		*AC_VO*	*(aCWmin + 1)/4-1*	*(aCWmin + 1)/2 − 1*
3		*AC_VI*	*(aCWmin + 1)/2-1*	*aCWmin*
2		*AC_BE*	*aCWmin*	*aCWmax*
1	Lowest priority level (highest contention window)	*AC_BK*	*aCWmin*	*aCWmax*

Table 2 MarPVS priority assignment based on TRDR and data type

No.	Default IEEE802.11p priority based on data type (designation)	MarPVS (TRDR)	MarPVS priority (designation)
1	*AC_VO*	Near (high)	*AC_SP*
2	*AC_VO*	Far (low)	*AC_VO*
3	*AC_VI*	Near (high)	*AC_VO*
4	*AC_VI*	Far (low)	*AC_VI*
5	*AC_BE*	Near (high)	*AC_VI*
6	*AC_BE*	Far (low)	*AC_BE*
7	*AC_BK*	Near (high)	*AC_BE*
8	*AC_BK*	Far (low)	*AC_BK*

lowest priority data type, with the maximum transmission time for one packet for each priority level. Therefore, number of concurrent low priority transmission, n_ρ for each priority level defined in MarPVS is derived in Eq. (9).

$$n_\rho = \frac{\Phi}{2}\sum_{\rho=1}^{\rho-1}\varphi_\rho \tag{9}$$

With number of concurrent low priority transmission derived, the average number of activity regions with number of concurrent low priority transmission with priority ρ and concurrent transmission n_ρ is defined in (10)

$$\bar{m}(n_\rho) = \sum_{m=1}^{n_\rho} mQ_m(n_\rho) \tag{10}$$

where $Q_m(n_\rho)$ is the probability distribution function of the number of activity regions with n_ρ concurrent transmission [41].

Using the average number of activity regions with number of concurrent low priority transmission, the overall average length of the sum of the activity regions with n_ρ concurrent transmission, and the average sum of interference sub regions with n_ρ concurrent transmission, are derived in MACVS as shown in (11) and (12).

$$External\ interference, P_{hMACVS} = \frac{P'_{hMAVCS}}{P'_{cMAVCS} + P'_{hMAVCS}} \tag{16}$$

TRDR represented by d_{MACVS} for the proposed joint optimization of MACVS are calculated based on received power defined in [42]. In (17) and (19), received power $P_r(d)$ and contention window size CW are derived, where $\hat{g}$ and $\hat{s}$ are introduced to assign weightings on transmission power and contention window size, with the conditions that the two parameters namely, change of SINR and received SINR do not exceed joint optimization costs defined by $\hat{J}_{\hat{g}}$ and $\hat{J}_{\hat{s}}$ These weightings are assigned to optimize transmission power and contention window.

Based on (17) and (19), d_{MACVS} is defined in (18), where G_t is the transmitting antenna gain, G_r is the receiving antenna gain, λ is the carrier wavelength and L is the system loss factor. Factors affecting the degradation of signal are included in the optimization weightings to determine the best optimized parameters. As defined, $G_t = 1$, $G_r = 1$, $\lambda = 2$ and $L = 1$ are usually taken [42].

$$Received\ power, P_r(d) = \frac{\hat{g} * P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{17}$$

$$l_{MACVS}(n_\rho) = \begin{cases} [2\bar{m}(n_\rho) + (0.5P_{cMACVS} + 1.5P_{hMACVS})(n - \bar{m}(n_\rho))]d & if\ n_\rho > 0 \\ 0, & if\ n_\rho = 0 \end{cases} \tag{11}$$

$$h_{MACVS}(n_\rho) = \begin{cases} \left[(1.5P_{cMACVS} + 0.5P_{hMACVS})\left(n - \bar{m}(n_\rho)\right)\right]d & if\ n_\rho > 0 \\ 0, & if\ n_\rho = 0, 1 \end{cases} \tag{12}$$

$$P'_{cMAVCS} = 1 - e^{-\lambda \varepsilon d_{MACVS}} \tag{13}$$

$$P'_{hMAVCS} = \frac{\lambda d_{MACVS}}{\lambda d_{MACVS} + \mu} \tag{14}$$

$$Internal\ interference, P_{cMACVS} = \frac{P'_{cMAVCS}}{P'_{cMAVCS} + P'_{hMAVCS}} \tag{15}$$

$$TRDR, d_{MACVS} = \sqrt{\frac{g * P_t G_t G_r \lambda^2}{(4\pi)^2 L P_r(d)}} \tag{18}$$

In MACVS, contention window size is assigned according to TRDR and data type as shown in Tables 1 and 2. The contention window size is assigned with weighting $\hat{s}$ defined in (20). Contention window size depicts the transmission opportunity for each node. Every transmission has a defined queue length and time to live (TTL) [43]. High queue length contributes to longer transmission opportunity delay. When the TTL expires due to over buffered, the packet is dropped.

In order to overcome this problem, a reduction in contention window size is necessary when low density of network traffics or harsh transmitting environment (high interference and noise) are detected. On the other hand, packet collision occurs when a high density of nodes transmitting packets measured by two parameters namely, change of SINR and received SINR, is detected in a region. To ensure that the node does not receive more packets than it can serve during traffic congestion, we increase the contention window size.

The weighting used to control the contention window size is denoted as $\hat{s}$. To ensure efficient contention window size optimization with priority levels defined in MarPVS, we propose to optimize the contention window size using (19). Contention window size is increased during traffic congestion or when high VANET environments' interference is encountered. On the other hand, contention window size is decreased during ease of traffic or when low VANET environments' interference is encountered. The contention window size is adjusted with an optimization parameter denoted as $\hat{s}$

$$Contention\ window, CW = CW_{min} + \hat{s}(CW_{max} - CW_{min}) \tag{19}$$

SINR is used to measure signal strength with respect to interference [1, 15, 16], which determines the transmission reliability. In MACVS, SINR is used to determine transmission reliability with (20). With transmission reliability, optimization parameters, $\hat{g}$ and $\hat{s}$ (21, 22) are calculated. In order to ensure optimal contention window size and transmission power, $\hat{g}$ and $\hat{s}$ are optimized to ensure minimal internal interference, P_{cMACVS} and external interference, P_{hMACVS}.

$$SINR = 10log_{10}\frac{\hat{g} * Transmission\ power}{P_{cMACVS} + P_{hMACVS} + Noise} \tag{20}$$

The joint optimization of transmission power and contention window size can be achieved with DP. The optimal contention window size and transmission power can be determined by running DP at each node. However, DP needs to conduct exhaustive search for all possible solutions at each interval which is time consuming and inefficient. This drawback makes it difficult to implement the optimal solution [44]. Therefore, in the following section, to overcome the complexity of DP in MACVS, we propose a low complexity and heuristic suboptimal control which strikes a balance between adequate performance and convenient implementation of DP algorithm.

3.2.2 Optimal control of the proposed MACVS

To ensure efficient MACVS, a low complexity DP algorithm is proposed. Transmission power and contention window size have major influence on the delay and packet success rate of transmission. In this section, the optimization of MACVS in terms of contention window size and transmission power is explained with a threshold based DP scheme.

Since the optimal transmission power and contention window size has a threshold structure related to SINR, therefore, we set the range of D in (21, 22) to be limited by thresholds, t and s. To ensure adaptability of MACVS, the thresholds t and s are adjusted according to VANET environments' interference and network traffics, denoted by SINR.

The weightings for transmission power, $\hat{g}$ and contention window size $\hat{s}$ are then derived as shown in (21, 22). The weightings are optimized to ensure minimal internal interference, P_{cMACVS} and external interference, P_{hMACVS}. The optimization is performed based on two parameters namely, change of SINR and received SINR. To ensure efficient optimization, the traffic conditions over a period of time [45] can be determined with the use of change of SINR, whereas traffic condition for an instant can be determined with the use of received SINR.

In (21) and (22), we propose a threshold based DP algorithm in determining the optimized parameters, $\hat{g}$ (for transmission power) and $\hat{s}$ (for contention window size). Using the proposed threshold based DP algorithm, the algorithm conducts a search for all possible solutions at each interval within a defined range depicted by range of D. The range of D is however, limited by thresholds t and s which is adjusted according to network traffic and environment conditions denoted by SINR.

$$\hat{g} = \min_{t \in D\hat{g}(\min,\max)}\{P_{cMACVS}\}\ and\ \min_{t \in D\hat{g}(\min,\max)}\{P_{hMACVS}\} \tag{21}$$

$$\hat{s} = \min_{s \in D\hat{s}(\min,\max)}\{P_{cMACVS}\}\ and\ \min_{s \in D\hat{s}(\min,\max)}\{P_{hMACVS}\} \tag{22}$$

3.2.3 Mathematical model for MACVS delay

In this section, with the use of optimal control threshold based DP and joint optimization, the delay for MACVS packet transmission is derived. In order to derive the packet transmission delay, we first derive the probability of high priority message in an activity region. When a source node generates a high priority message, it may be located in an activity region [41]. Thus, probability of such event with proposed $l_{MACVS}(n_\rho)$ and $h_{MACVS}(n_\rho)$ is defined as $P_{i(\rho)MACVS}$.

$$P_{i(\rho)MACVS} = \sum_{j=1}^{n_{\rho\max}} h_{\rho MACVS}(j)/l_{\rho MACVS}(j)p_{n_\rho}(j) \quad (23)$$

With the probability of high priority message in activity region, the average sum of active regions is derived. The average sum of active regions, $l_{MACVS}(n_\rho)$ is affected by P_{hMACVS} whereas average sum of interference sub regions, $h_{MACVS}(n_\rho)$ depends on P_{cMACVS}. Therefore, with reference to (15), (16) and (23), to ensure minimal internal and external interferences, (P_{cMACVS} and P_{hMACVS}), minimal delay, maximum P'_{cMACVS} and minimal P'_{hMACVS} must be retained to minimize probability of a source node located in an activity region during generation of high priority message.

With priorities defined in MarPVS, the birth rate of number of concurrent transmission when state of system in (n_ρ, k_ρ) is defined in (24)

$$\alpha_{n_\rho|k_\rho}(n_\rho) = \lambda_\rho\left(\Phi - \frac{k_\rho}{R}\right)(R - l_{MACVS}(n_\rho)) + \frac{k_\rho\beta}{R}(R - l_{MACVS}(n_\rho)) \quad (24)$$

where $R =$ total highway length and $\Phi =$ total number of vehicles, $k_\rho =$ probability of low priority transmission occurs when transmission of high priority takes place, where $\lambda_\rho =$ Poisson arrival rate for different priority level, $\beta = \frac{1}{\alpha\omega_\rho}$, $\alpha =$ backoff time slot, $\omega_\rho =$ backoff contention window size for different traffic class, $l_{MACVS}(n_\rho)$ = the overall average length of the sum of the activity regions with n_ρ concurrent transmission.

The death rate of number of concurrent transmission when state of system is in $((n_\rho, k_\rho)$, with priority defined by MarPVS in (24) is denoted in (25)

$$b_{n_\rho|k_\rho}(n_\rho) = n_\rho\bar{\mu}_\rho \quad (25)$$

where $\lambda_\rho =$ Poisson arrival rate for each MarPVS priority level, $\alpha =$ backoff time slot, $\beta = \frac{1}{\alpha\omega_\rho}$, $\omega_\rho =$ backoff contention window size for each traffic class, $\bar{\mu}_\rho =$ transmission time of a message for different traffic classes which is exponentially distributed with parameter $\bar{\mu}_\rho$. With exponential arrival rates, the Markovian birth–death process in [41] with MarPVS different priority level is modelled in (26).

$$(n_\rho|k_\rho) = P_0|k_\rho \prod_{i=0}^{n_p} \frac{a_{i|k(i)}}{b_{i+1|n_\rho(i+1)}} \quad 0 \le n_\rho \le n_{\rho max} \quad (26)$$

With Markovian birth and death equations, in (27), we derived the probability that no new low-priority transmission starts in the transmission range of a forwarding node within a time slot, α.

$$P_s(n_\rho, k_\rho) = e^{-r_{n_\rho,k_\rho}\alpha} \quad (27)$$

With known probability of no low priority transmission starts in the transmission range of a forwarding node within time slot, α, we derived the unconditional probability of $P_s(n_\rho, k_\rho)$ that within a time slot, no new low priority transmission starts in a transmission range of a forwarding node for all MarPVS priority levels in (28).

$$P_{s(\rho)} = \sum_{k_\rho=0}^{n_\rho\, max} \sum_{n_\rho=0}^{n_\rho\, max} e^{-\Gamma_{n_\rho,k_\rho}\alpha}\, \rho_{n_{\rho|k_\rho}}(n_\rho|k_\rho) \quad (28)$$

The forwarding delay is defined as $\alpha + \bar{x}_\rho$ if the medium is free and the node proceeds with transmission of packets. On the other hand, the forwarding delay is defined as $0.5\alpha + \bar{x}_\rho + E_\rho[backoff\ time] + \bar{x}_\rho$ if the medium is busy and defers transmission after completion of ongoing transmission inclusive of a back off process.

With known forwarding delay, the average delay experienced by the ith forwarding node for each priority level in MarPVS [38] as the consequence of a single back off procedure in the broadcasting mode is derived in (29). Equation (29) is defined where the slot is randomly selected with $E_\rho[backoff\ time] = \frac{\omega_\rho}{2}T_{st(\rho)}$, $\bar{x}_\rho = \varepsilon_\rho e^{-d\mu_\rho} - \varepsilon_\rho$, ${}_\varepsilon\varepsilon_\rho = \frac{\varsigma}{\mu-\lambda}\left(\frac{1}{b}\bar{P}_\rho\right)$ and $\bar{b} < 1$.

$$\bar{d}_{h(\rho)} = P_{s(\rho)}(\alpha + \bar{x}_\rho) + (1 - P_{s(\rho)})(0.5\alpha + \bar{x}_\rho + E_\rho[backoff\ time] + \bar{x}_\rho) \quad (29)$$

The average waiting time for each counted slot shown by forwarding delay for each priority level in MarPVS is derived in (30) with the assumption that transmission may start with probability $1 - P_{s(\rho)}$ within a slot duration.

$$T_{st(p)} = P_{s(\rho)}\alpha + (1 - P_{s(\rho)})(0.5\alpha + \bar{x}_\rho + T_{st(\rho)}) \quad (30)$$

Thus, probability of a source node generates a high priority message while located in an activity region as discussed in [4] is derived as $P_{i(\rho)MACVS}$ in (31).

$$P_{i(\rho)MACVS} = \sum_{j=1}^{n_{\rho max}} h_\rho(j)/l_\rho(j)p_{n_\rho}(j) \quad (31)$$

Since within an activity region, arrival of high priority message is randomly distributed. On the other hand, if the source node is located in non- activity region, it experiences delay similar to a forwarding node as defined in (23). For that reason, the average delay $\bar{D}_{\rho MACVS}$ experienced by the ith forwarding node in each priority level in MarPVS defined in MACVS is derived in (32).

$$\bar{D}_{\rho MACVS} = P_{i(\rho)MACVS}\left[\frac{\omega_\rho}{2}T_{st(\rho)} + 1.5\bar{x}_\rho\right] + \left(1 - P_{i(\rho)MACVS}\right)\bar{d}_{h(\rho)} \quad (32)$$

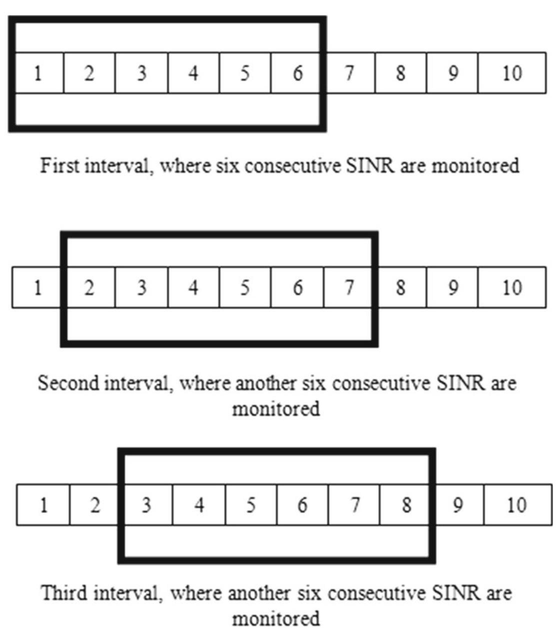
3.2.4 MACVS pseudocode

In order to further explain the overall MACVS, an overall pseudocode is used to elaborate MACVS in this section. As shown in Fig. 3a, b, we proposed an implementation of a joint optimization with MarPVS priorities defined in pseudocode 1, and joint optimization scheme defined in pseudocode 2.

MarPVS assigns priorities based on two parameters namely, TRDR and data type. Since transmission has higher packet success rate when in close proximity, MarPVS which assigns higher priority for short TRDR transmission according to data type improves the overall packet scheduling efficiency. To the best of our knowledge, no joint threshold structure DP with closed loop feedback control system on contention window size and transmission power optimization, based on continuous observation on traffic, interference and transmission reliability, denoted by two parameters namely, received SINR and change of SINR, has been proposed in VANET MAC applications.

The above optimal transmission power and contention window size can be achieved by running DP in each interval. By applying the principle of DP, in pseudocode 2, we introduce two parameters namely, change of SINR and received SINR, to determine weightings $D_{\hat{s}_{min}}$ and $D_{\hat{g}min}$ for contention window size and transmission power respectively. Within a transmission range, fluctuations of SINR depict network conditions and the transmission

(a)



(b)

Input: Data type (Contention Window and Transmission Power)
Output: Delay, Packet Success Rate

While (“messages are received”) do

Algorithm 1: Assignment of Priority (MarPVS)
foreach *Time* do
If ((transmission reliability==High)&&(priority==AC_VO)),
newpriority = AC_SP
else If ((transmission reliability==High)&&(priority==AC_VI)),
newpriority = AC_VO
else If ((transmission reliability==High)&&(priority==AC_BE)),
newpriority = AC_VI
else If ((transmission reliability==High)&&(priority==AC_BK)),
newpriority = AC_BE
else
newpriority = priority
end
end

for (s=$D_{\hat{s}min}$; $s < D_{\hat{s}max}$; s++)
for (t=$D_{\hat{g}min}$; $t < D_{\hat{g}max}$; t++)
find s and t with minimum P_{cMACVS} and P_{hMACVS}
end
end
end

Algorithm 2: Joint Optimization (MACVS)
foreach *Time* do
Calculate *Change of SINR and SINR Threshold*
If ((*Change of SINR = positive*) && (*SINR* > $Threshold_{S1}$)),
$Rate = Increase$,
$D_{\hat{s}min} = \hat{s}_{min}/2, D_{\hat{s}max} = \hat{s}_{max}/2$
$D_{\hat{g}min} = \hat{g}_{min}/2$, $D_{\hat{g}max} = \hat{g}_{max}/2$
else if ((*Change of SINR =negative*) &&(*SINR*<$Threshold_{S2}$)),
$Rate = Decrease$,
$D_{\hat{s}min} = 2\hat{s}_{min}, D_{\hat{s}max} = 2\hat{s}_{max}$
$D_{\hat{g}min} = 2\hat{g}_{min}, D_{\hat{g}max} = 2\hat{g}_{max}$
else
$Rate = Same$,
$D_{\hat{s}min} = \hat{s}_{min}, D_{\hat{s}max} = \hat{s}_{max}$
$D_{\hat{g}min} = \hat{g}_{min}, D_{\hat{g}max} = \hat{g}_{max}$
end

for (s=$D_{\hat{s}min}$; $s < D_{\hat{s}max}$; s++)
for (t=$D_{\hat{g}min}$; $t < D_{\hat{g}max}$; t++)
find s and t with minimum P_{cMACVS} and P_{hMACVS}
end

Fig. 3 **a** Timing chart of a sliding window where $i = 6$. **b** MACVS pseudocode

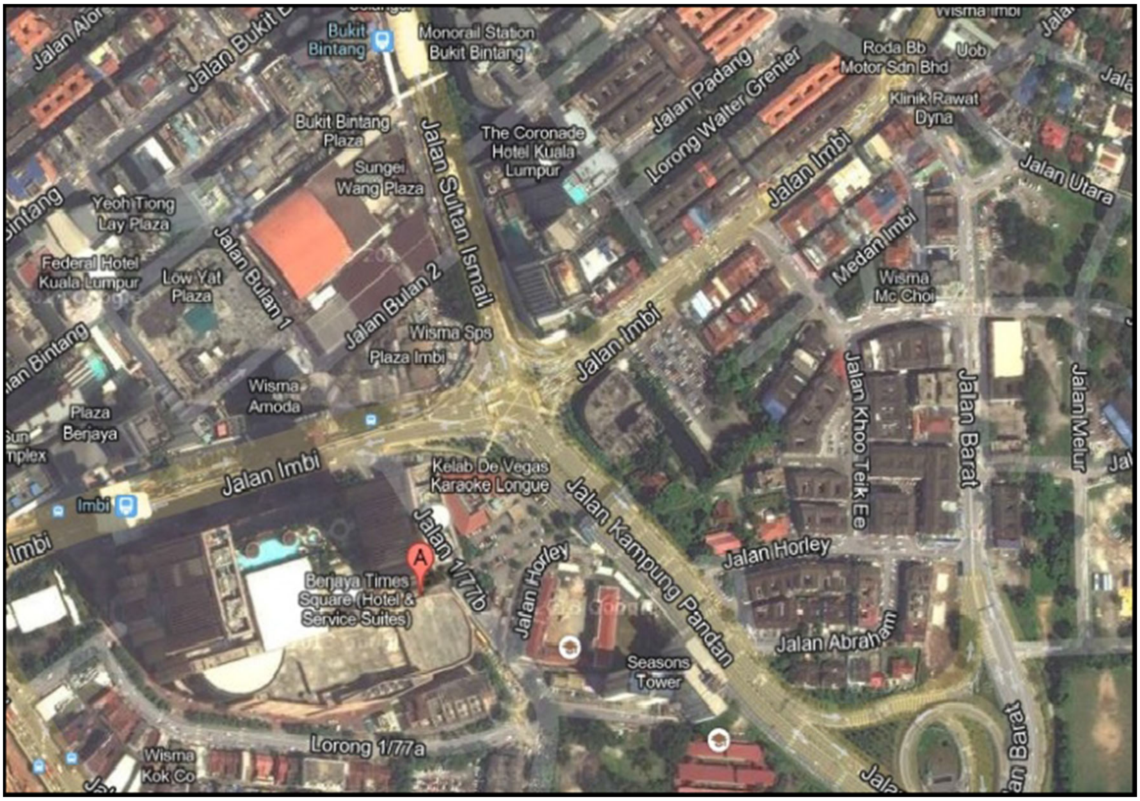


Fig. 4 Kuala Lumpur, Malaysia city centre map (an urban area)

Table 3 Traffic parameters

Parameter	Value
Packet arrival rate, λ	0.01–0.001 s
Number of vehicles, $Đ$	30–150
Packet size	512 bytes
Transmitted power	19 dBm
Time for each slot, δ	0.000013 s
Interval, i	6
Interval, j	6
Threshold, r	50 m
$Threshold_{S1}$, $Threshold_{S2}$	5, 2 dB
$\hat{s}_{min}$, $\hat{s}_{max}$	0.6, 1.2
$\hat{g}_{min}$, $\hat{g}_{max}$	0.6, 1.2
Number of events, $\check{n}$	50,000

environment the node is located in. Local traffic, transmission reliability and VANET environment changes, can thus be indicated using two parameters namely, change of SINR and received SINR.

For simplicity, MACVS DP has a threshold structure related to SINR. We set the range of $D_{\hat{s}min}$ and $D_{\hat{g}_{min}}$ limited by a threshold depicted by SINR. We monitor the received SINR for an i consecutive intervals as shown in Fig. 3a.

If the received SINR increases and is above a threshold value, we minimize the DP search to lower weightings range. On the other hand, if the received SINR decreases, and is below a threshold value, we minimize the DP search to higher weightings range. For constant threshold SINR, weightings range is maintained. Our ultimate goal is to find weightings with minimum P_{cMACVS} and P_{hMACVS} to minimize the total expected delay based on the derived equations in previous section, The pseudocode for the proposed MACVS is shown in Fig. 3b.

4 Simulation and analytical results

In this section, we present illustrative numerical results and simulated results with regards to the analysis proposed in the previous section. The performance of the proposed MACVS is evaluated with the use of Matlab, Omnet-4.2.2, Vehicles Network Simulation (Veins), Simulation of Urban Mobility (SUMO) and open google map applications [46].

An event driven platform for mathematical analysis in Sect. 3.2 was developed with the use of Matlab. On the other hand, VANET MAC with MACVS simulation was developed using Omnet-4.2.2, Veins and SUMO, continuous road traffic simulation designed to handle large road

Table 4 Complexity measurement

	Run time (s)	Percentage of increased run time (%)
Default IEEE802.11p Scheme	20.9041	–
Reference Scheme in [4]	20.9882	0.4023
MACVS without threshold structured DP	21.1485	0.8324
The proposed MACVS with threshold structured DP	20.9745	0.3368

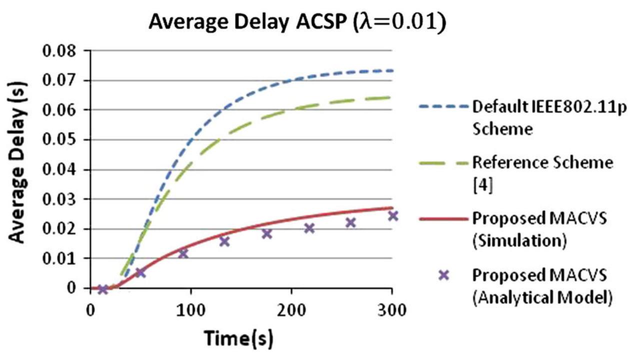


Fig. 5 Average delay ACSP (λ = 0.01—congestion free traffic)

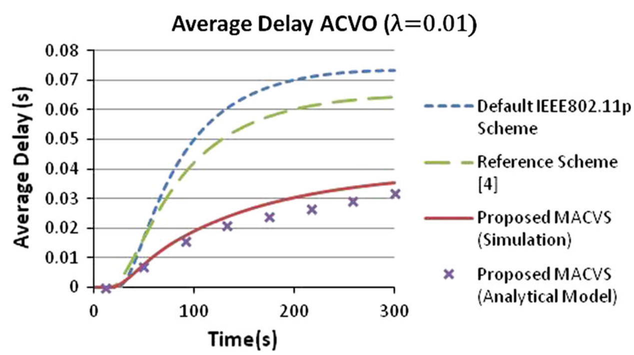


Fig. 6 Average delay ACVO (λ = 0.01—congestion free traffic)

networks in a real life urban map of Kuala Lumpur, Malaysia as shown in Fig. 4. Multiple independent simulations were performed where statistics were collected once the system had reached steady state. Table 3 shows the parameters used in the simulation.

Using simulations, we compared the complexity of the proposed MACVS with default IEEE802.11p scheme and reference scheme in [4]. Complexity of the default IEEE802.11p scheme, the reference scheme in [4] and the proposed MACVS are measured with run time and ň number of events with the use of Intel Core I3 Processor, 4 GB RAM and Microsoft Windows 8 platform. In Table 4, the proposed MACVS with threshold structured DP shows low complexity as compared to the default IEEE802.11p scheme and reference scheme in [4].

By taking two different arrival rates into consideration, we simulated the performance of MACVS to test its adaptability. The first arrival rate denotes a congestion state whereas the second arrival rate denotes a congestion free state.

Figures 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14 show the simulation and analytical results for congestion free traffics whereas Fig. 15, 16, 17, 18, 19, 20, 21, 22, 23 and 24 show the simulation and analytical results for congested traffics.

With DP optimized transmission power and contention window size proposed in MACVS, from Figs. 5 6, 7, 8 and 9, and Figs. 15 16, 17, 18 and 19, we observe an improvement in average delay in MACVS as compared to the default IEEE802.11p scheme and the reference scheme in [4].

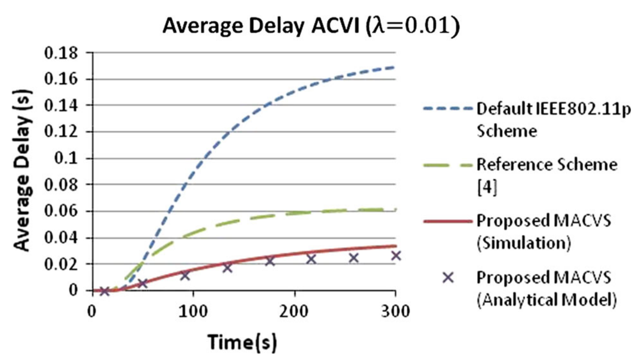


Fig. 7 Average delay ACVI (λ = 0.01—congestion free traffic)

In MACVS, the two control parameters namely, change of SINR and received SINR, are used to optimize transmission power and contention window size with threshold DP structure. With the use of joint optimization of transmission power and contention window size with reference to real time traffic control, packet scheduling becomes adaptable.

Proper assignment of transmission power and contention window size improves overall packet transmission with the application of threshold based DP. Therefore, with efficient, less time consuming MACVS optimization, improvements in terms of packet scheduling and adaptability are observed. With better packet scheduling and adaptability, we observe a reduction in delay and an increment of packet success rate. With an adaptable contention window size and transmission power, MACVS has shown to achieve better packet transmission performance

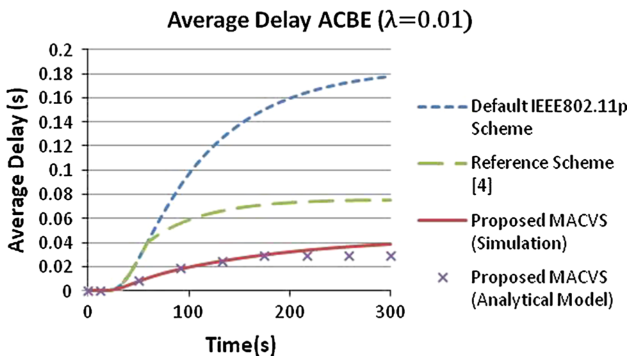


Fig. 8 Average delay ACBE (λ = 0.01—congestion free traffic)

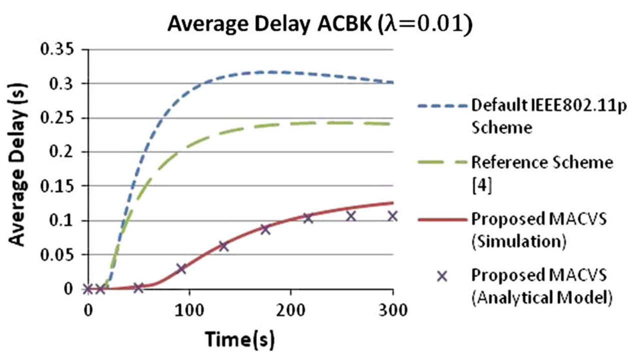


Fig. 9 Average delay ACBK (λ = 0.01—congestion free traffic)

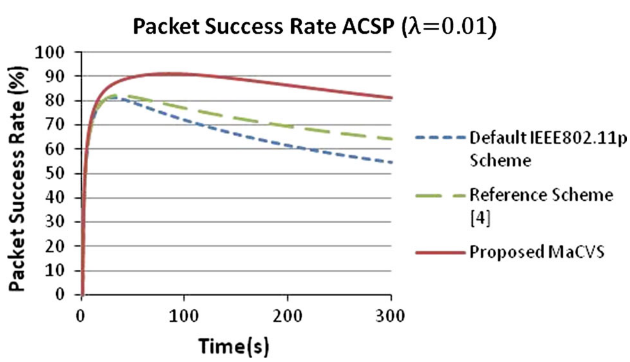


Fig. 10 Packet success rate ACSP (λ = 0.01—congestion free traffic)

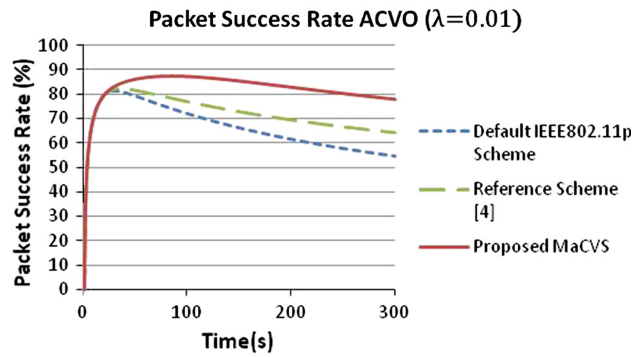


Fig. 11 Packet success rate ACVO (λ = 0.01—congestion free traffic)

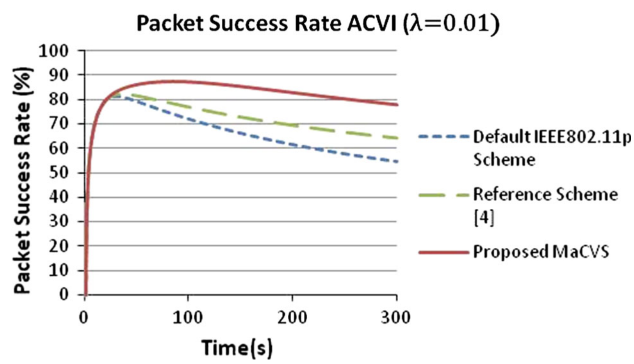


Fig. 12 Packet success rate ACVI (λ = 0.01—congestion free traffic)

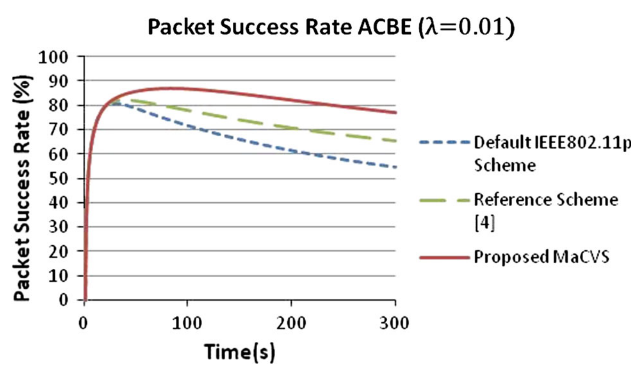


Fig. 13 Packet success rate ACBE (λ = 0.01—congestion free traffic)

making it adaptable to various environment and traffic conditions which is an important application in VANET.

To elaborate on the simulation findings, effects of improper assignment of contention window size and transmission power are discussed here. It is noticed that an excessively high transmission power causes high interference which creates hidden terminal issues. These hidden terminals cause transmissions to take place without the knowledge of the existing hidden nodes which contribute to high delay and packet loss. On the other hand, a low transmission power with low signal strength may result in transmissions unable to reach its destination node. It is also noticed that high contention window size in VANET prevents transmission collisions in a highly congested traffic. On the other hand, a low contention window size allows more transmission in a congestion free traffic.

In MACVS, we observe lower delay and higher packet success rate from Figs. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15,

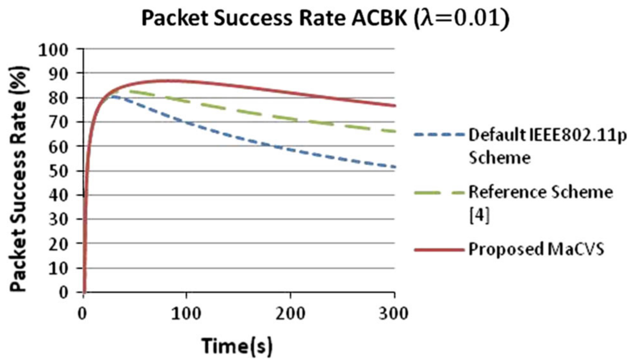


Fig. 14 Packet success rate ACBK (λ = 0.01—congestion free traffic)

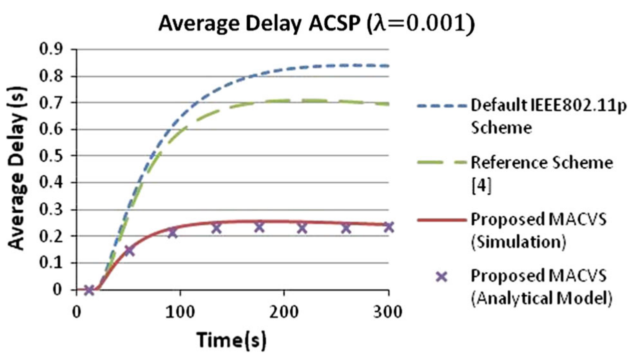


Fig. 15 Average delay ACSP (λ = 0.001—congested traffic)

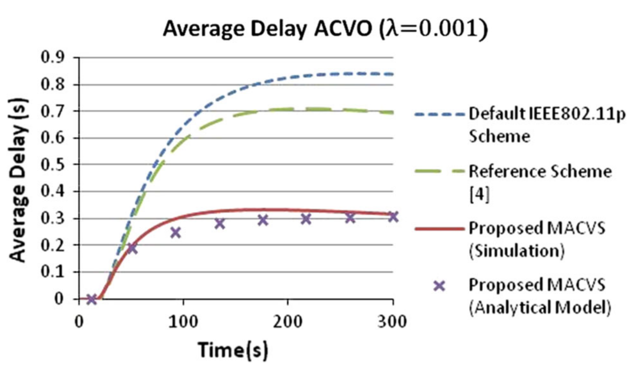


Fig. 16 Average delay ACVO (λ = 0.001—congested traffic)

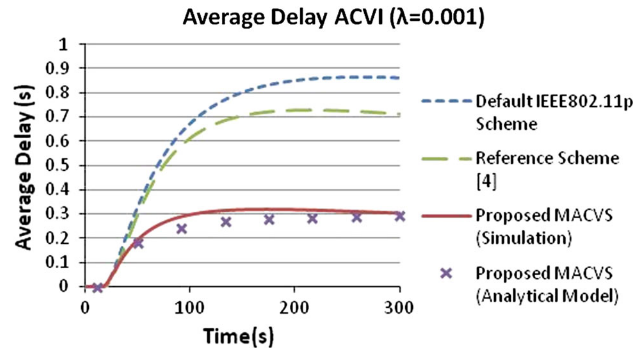


Fig. 17 Average delay ACVI (λ = 0.001—congested traffic)

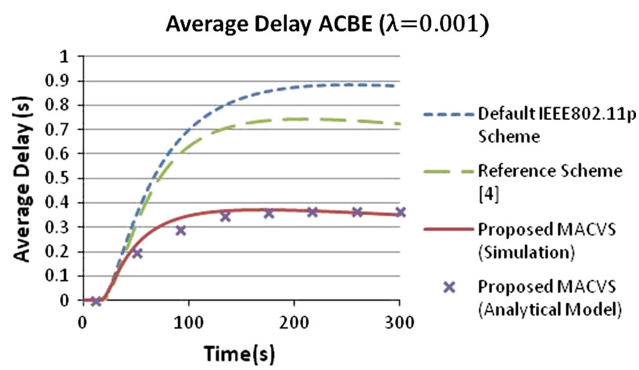


Fig. 18 Average delay ACBE (λ = 0.001—congested traffic)

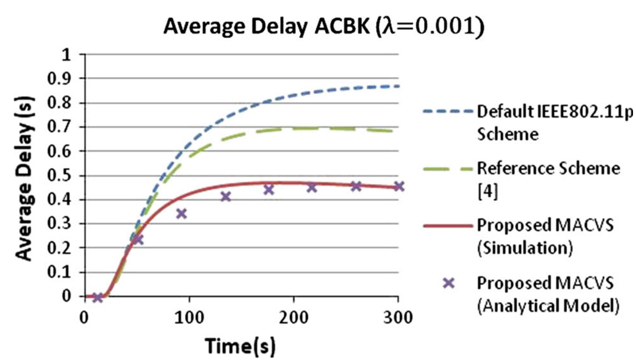


Fig. 19 Average delay ACBK (λ = 0.001—congested traffic)

16, 17, 18, 19, 20, 21, 22, 23 and 24. The joint optimization in MACVS ensures fewer queues at the destination node. With fewer queues, average waiting time for each packet is reduced. Therefore, packets are well scheduled and thus, average delay is reduced. Packets do not have to wait a long period of time to be processed at the destination node. With shorter queuing and transmission delay, the time to live (TTL) period threshold is not exceeded. Thus, packets have higher chance to be successfully transmitted to its destination node.

With higher packet success rate, the number of dropped packets reduces and the overall packet transmission improves with proper scheduling and adaptability of MACVS. Therefore, we observe lower delay in Figs. 5, 6, 7, 8, 9 and Fig. 15, 16, 17, 18, 19, and higher packet success rate in Figs. 10, 11, 12, 13, 14 and Fig. 20, 21, 22, 23, 24, for MACVS

The analysis of the MACVS delay is elaborated in the mathematical model. The mathematical model for the proposed MACVS shows the lower bound average delay. The lower bound average delay represents minimum

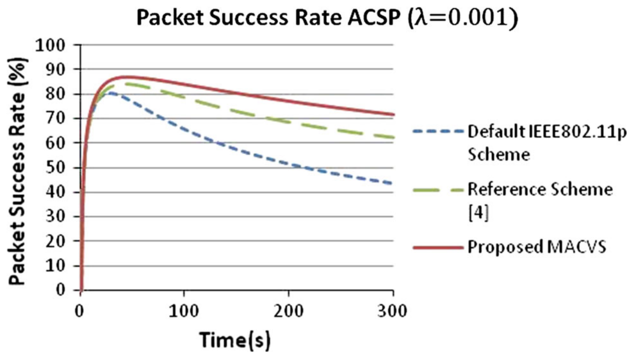


Fig. 20 Packet success rate ACSP (λ = 0.001—congested traffic)

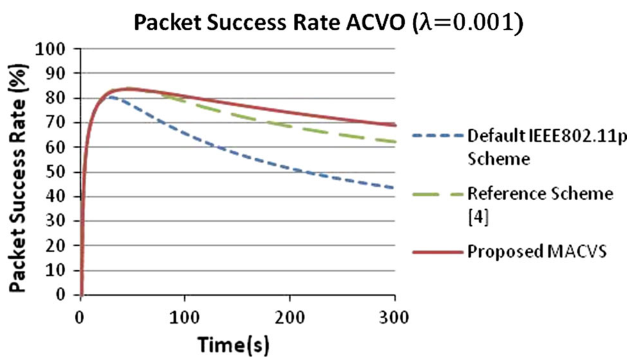


Fig. 21 Packet success rate ACVO (λ = 0.001—congested traffic)

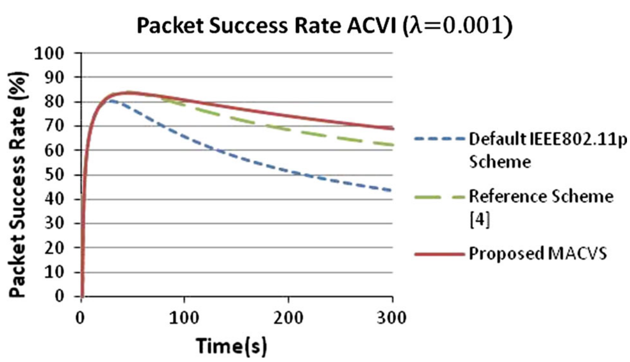


Fig. 22 Packet success rate ACVI (λ = 0.001—congested traffic)

average delay which was derived based on mathematical expressions discussed in the previous sections. We observe a good agreement between the mathematical and simulated results for MACVS in Figs. 5, 6, 7, 8, 9, and Figs. 15, 16, 17, 18, 19. Numerical and simulation results confirm the accuracy of the proposed analysis.

5 Conclusion

VANET is an emerging technology that is soon to be deployed in every car network. Car network should be made adaptable to cater for the varying environment and nature of

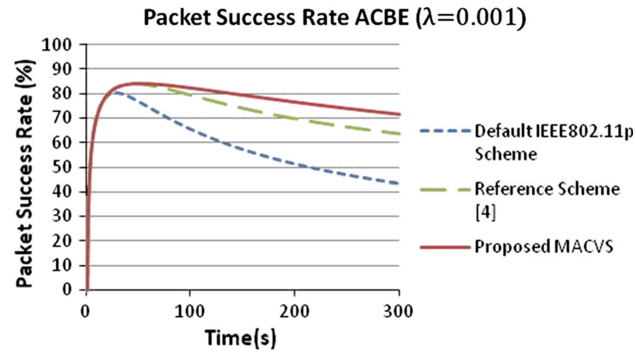


Fig. 23 Packet success rate ACBE (λ = 0.001—congested traffic)

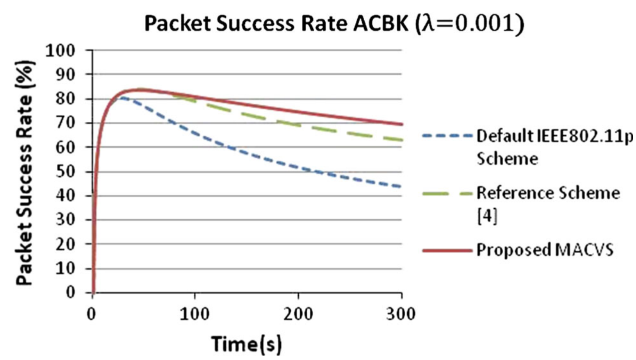


Fig. 24 Packet success rate ACBK (λ = 0.001—congested traffic)

VANET. Therefore, an adaptable MAC is important to ensure transmission efficiency in VANET. In this chapter, a joint threshold structure DP optimization scheme (MACVS) is formulated to ensure VANET adaptability. Using a closed loop feedback control system and a joint threshold structure DP optimization scheme with two parameters namely, the change of SINR and received SINR, the two outputs namely, contention window size and transmission power, are optimized according to network traffic and VANET transmission environment. The main objectives of MACVS are to minimize average delay and maximize packet success rate in varying nature of VANET. Taking the computational limitation of nodes into considerations, a low complexity threshold based DP with heuristic contention window size and transmission power control (MACVS) is proposed to reduce the computational complexity of running a full DP algorithm. A five levels priority scheme, MarPVS is adapted as part of MACVS to ensure emergency messages get transmitted on time.

Using mathematical analysis, the effects of interference in end to end delay are analyzed. To ensure realistic and accurate analysis, simulations are done with an urban map of Kuala Lumpur, Malaysia. Results show the adaptability of MACVS which makes it suitable for VANET applications.

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Joanne Mun-Yee Lim received her Bachelor of Engineering (with honours) from Monash University in 2008 and her Master of Engineering Degree from University Malaya in 2011. She is also a member of The Institution of Engineers Malaysia and a professional engineer of the Board of Engineers Malaysia. Currently, she is pursuing her Ph.D. in Engineering in Multimedia University. She joined the Department of Electrical Engineering in University Malaya as a tutor in 2010. She is currently a Lecturer in the Department of Engineering in SEGi University. Her research interest includes Vehicular Ad hoc Network (VANET), mobile IPv6 based networks, artificial intelligence, control systems, optimization schemes, robotic design and applications.

Yoong Choon Chang joined Multimedia University Malaysia in 2001 and is currently a senior lecturer in the Faculty of Engineering. He received his B.Eng. (First Class Honours) in Electrical and Electronic Engineering from Northumbria University, UK, M.Eng.Sc. and Ph.D. (Engineering) from Multimedia University. Besides academic teaching, he is also the head of Digital Home Lab, which was setup the Malaysian Communications and Multimedia Commission, in collaboration with Multimedia University, Telekom Malaysia and other industry partners in 2008. As the head of the research lab, his responsibilities include supervising postgraduate research students and laying out the future research direction of the lab so that the research outcome of the lab benefits the parent company, Telekom Malaysia. His main research interests are multimedia communications and computer vision techniques in ambient assisted living, with four postgraduate by research students under his current supervision and six have graduated. His research work has been funded by Asia–Pacific Telecommunity, Malaysian Communications and Multimedia Commission, Telekom Malaysia, Ministry of Science, Technology and Innovation Malaysia. He has more than 30 scientific publications in international journals and conferences.

Mohamad Yusoff Alias was born in Selangor, Malaysia in 1971. He completed his Pre-university education at Tulsa English Institute, Tulsa, USA (August–December 1994) and University of Tulsa, Tulsa, USA (Spring 1994). He graduated with B.Sc. in Engineering (Electrical Engineering) in 1998 from the School of Electrical, Electronics and Computer Science (EECS), University of Michigan, Ann Arbor, Michigan, USA, and Ph.D. specializing in Wireless Communication in 2005 from School of Electronics and Computer Science (ECS), University of Southampton, UK under the supervision of Professor Lajos Hanzo and Professor Sheng Chen. His thesis title is "Minimum Bit Error Rate Multiuser Detection for Multiple Antenna Aided Uplink OFDM". He is an Associate Professor and at present, the Associate Dean at the Faculty of Engineering, Multimedia University. His main research interests are in Orthogonal Frequency Division Multiplexing (OFDM), Wireless Security and Radio-over-Fiber. Dr. Alias is a member IEEE since 2004, a graduate member of The Institute of Engineers Malaysia (IEM) since 2000, a registered member of Board of Engineers Malaysia (BEM) since 1999, and member of Eta Kappa Nu (HKN), Beta Epsilon Chapter since 1997.

Jonathan Loo a.k.a. Kok-Keong Loo received the M.Sc. degree in electronics (with distinction) and the Ph.D. degree in electronics and communications from the University of Hertfordshire, Hertfordshire, U.K., in 1998 and 2003, respectively. Between 2003 and 2010, he was a Lecturer in multimedia communications at the School of Engineering and Design, Brunel University, Uxbridge, U.K. Since 2010, he has been an Associate Professor in communication networks with the School of Science and Technology, Middlesex University, London, U.K. He is also an Adjunct Associate Professor at Multimedia University, Malaysia. Dr. Loo leads a research team in the area of communication and networking. His research interests include wireless communication, network architecture, communication protocols, wireless and mobile networks, network security, embedded systems, video coding and transmission, digital signal processing, and optical networks. He has successfully graduated 13 Ph.D. students and coauthored over 160 both journal and conference papers in the aforementioned specialist areas. He was the Lead Editor of the book Mobile Ad Hoc Networks: Current Status and Future Trends (CRC Press, November 2011). Dr. Loo has been an Associate Editor for Wiley International Journal of Communication Systems since 2011.