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Performance Modelling of Adaptive VANET with Enhanced Priority Scheme

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Abstract

In this paper, we present an analytical and simulated study on the performance of adaptive vehicular ad hoc networks (VANET) priority based on Transmission Distance Reliability Range (TDRR) and data type. VANET topology changes rapidly due to its inherent nature of high mobility nodes and unpredictable environments. Therefore, nodes in VANET must be able to adapt to the ever changing environment and optimize parameters to enhance performance. However, there is a lack of adaptability in the current VANET scheme. Existing VANET IEEE802.11p's Enhanced Distributed Channel Access; EDCA assigns priority solely based on data type. In this paper, we propose a new priority scheme which utilizes Markov model to perform TDRR prediction and assign priorities based on the proposed Markov TDRR Prediction with Enhanced Priority VANET Scheme (MarPVS). Subsequently, we performed an analytical study on MarPVS performance modeling. In particular, considering five different priority levels defined in MarPVS, we derived the probability of successful transmission, the number of low priority messages in back off process and concurrent low priority transmission. Finally, the results are used to derive the average transmission delay for data types defined in MarPVS. Numerical results are provided along with simulation results which confirm the accuracy of the proposed analysis. Simulation results demonstrate that the proposed MarPVS results in lower transmission latency and higher packet success rate in comparison with the default IEEE802.11p scheme and greedy scheduler scheme.

Keywords: VANET, Priority, Transmission Distance Reliability Range, Contention Window, Markov Model

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1. Introduction

VANET is emerging as a potential promising technology in providing wireless vehicles communication to ensure safety and comfort applications for drivers [1]. Nodes in VANET are prone to unpredictable environments due to its inherent nature of high mobility. A node in VANET might move from a congested channel to a less congested channel within a short period of time. Hence, to enhance data transmission within a channel filled with high mobility nodes, TDRR and type of transmissions are two important parameters used to classify and prioritize data transmission. With optimized and adaptable data transmission, scheduling in traffic congestion becomes efficient and thus, reliable transmission of safety messages can be guaranteed. Safety messages can be categorized into periodic and event-driven applications. The first category namely periodic application has an informative nature as messages are periodically disseminated to inform drivers on local parameters such as speed and location. The second category namely event driven applications are broadcasted when a specific node discovers or experiences an unusual event or hazard. Such application has the highest priority in VANET. In a steady state environment, periodic broadcast message are expected to constitute a major part of the channel which reduces resource availability for high priority message transmission. If a vehicle misses an event driven safety message from a close distanceneighboring node, the consequences may be catastrophic.

Studies in [2] and [3] show that accidents are more likely to occur when vehicles are in close distance. Hence, in our proposed MarPVS, data transmissions are prioritized according to data type and TDRR to allow event driven safety messages from a close TDRR neighboring node to transmit first. Since vehicles in VANET are highly mobile, priorities assigned during transmission would have been obsolete upon reaching its destination node. As such, we use Markov model to predict the future TDRR between communicating vehicles based on past data obtained. Since TDRR between vehicles and transmission data type play a major role in determining transmission latency and efficiency in VANET, in the proposed MarPVS, we categorize five priority levels according to TDRR and data types. These priorities can be assigned with the use of contention window size. Contention window size is defined as the waiting period which separates between packet transmissions. If the contention window is longer, the packet has to wait a longer period before the next transmission. If the contention window is shorter, the packet waits for a shorter period of time before the next transmission, hence the packet transmission has higher priority.

Having said that, based on five priority levels defined in MarPVS, we developed an analytical model for the communication of different priority traffics. When a message is generated in an idle node, if the medium is free for a distributed frame space (DIFS), the message is transmitted immediately. Otherwise, the back off counter is randomized and decremented for each idle contention slot detected. When the back off counter reaches zero, the next transmission attempts to transmit in the next contention slot. Messages arrive to the idle nodes located in activity regions results in back off initiation whereas messages arrive at the idle nodes located in non-activity regions are allowed to transmit immediately.

Since the back off counter is set to an integer randomly drawn from contention window and contention window is selected based on priority of transmission, hence, probability of successful packet transmission in each priority can be derived from minimum number of packets transmitted within maximum contention window size for each priority and maximum transmission slots for one packet in each priority. Based on probability of successful packet transmission for each priority level, we can derive the number of low priority messages in back off process and number of concurrent low priority transmission [4] for each MarPVS priority level. In addition, the average transmission time for each priority can be deduced from priority queuing delay and arrival rate. Using Markovian birth- death process analysis in [5], we then derive the final average transmission delay for each priority level.

The main contributions of this work are as follows: Firstly, we propose a Markov model prediction scheme to predict future TDRR between communicating vehicles. Vehicles in VANET are highly mobile; priorities assigned during transmission would have been obsolete upon reaching its destination node. Therefore, we propose to use Markov model prediction scheme to predict future TDRR based on past data traffics. The analytical TDRR prediction using Markov model is verified with simulated data. Secondly, since vehicles in close proximity are prone to accidents, we propose to assign the highest priority level to vehicles' data traffics in close TDRR, sending highest priority emergency messages. Thirdly, since reliability of transmissions increases between close TDRR transmissions, we propose to increase all priority levels for data transmission in close proximity by one level to ensure priorities are given to communication between close range vehicles and to reduce delay. Fourthly, we perform an analytical study on the performance modeling of MarPVS. We derived the maximum transmission slots, minimum number of packets transmitted within maximum contention size, probability of successful transmission, number of low priority messages in back off process, number of concurrent low priority transmission and average packet transmission time for five priority levels defined in MarPVS. Finally, results obtained are used to derive average transmission delay for five priority levels defined in MarPVS. With Markov model TDRR prediction and MarPVS priority levels, we observed improvements in percentage of packet loss and average end to end delay. MarPVS has also shown to be adaptable and applicable for various application such as vehicle to vehicle (V2V), vehicle to insfrastructure (V2I), control and service channel.

The rest of the paper is organized as follows. Section 2 discusses the related work. Section 3 explains the MarPVS algorithm. Section 4 presents the main analysis and performance modeling based on MarPVS. Section 4 discusses simulation parameters, analytical and simulation results. Section 5 concludes the paper.

2. Related Work

In VANET, 5.9 Ghz is used in wireless access vehicular environment (WAVE) standard to assign communication links between WAVE devices. Medium access control (MAC) plays a vital role in controlling priority access and transmission of messages protocols. In this section, we discuss some of the recent work.

Priority allocations in VANET determine the VANET efficiency as a whole. In [6], a protocol is developed where area inside the transmission range is repetitively divided to assign priority forwarding duty vehicle in the closest range. In [7], a new scheduling algorithm with greedy scheduler is proposed to serve traffics with higher level of priority sooner than other traffics. The scheduler consists of two parts, the first part is responsible in ensuring target queue of each packet is based on priority field whereas the second part is responsible in ensuring packets with the shortest time restriction deadline serves first. In [8], priorities are adjusted for different allocated users depending on traffic types. In [9], different back off time spacing is proposed in order to allow higher priority messages to have the privilege to access transmission medium quicker than lower priority messages. Priority schemes discussed in the aforementioned literature are assigned solely based on data type. However, accidents are prone to happen between vehicles in close distance. Therefore, ensuring reliable data transmission between close distance vehicles is important to ensure emergency messages get transmitted in time. As such, in our proposed scheme, TDRR and data type are used to determine priority levels. However, in VANET, vehicles are constantly on the move, thus vehicles' TDRR would have obsolete upon reaching its destination node. Therefore, a prediction on the future anticipated location of vehicles are essential to ensure priorities are assigned accordingly and do not obsolete upon reaching its destination node. In this context, Markov model is implemented to predict TDRR between vehicles for priorities assignment.

Markov model has been widely used to perform probabilistic approach in determining a prediction process. In [10], a Markov process is used to determine the propagation distance which inherently demonstrates the suitability of Markov for TDRR prediction used in our proposed MarPVS. As discussed in [11], probabilistic prediction of road traffic is addressed where Markov is proven to be a better probabilistic approach as compared to Monte Carlo approach. Subsequently, in [12], a robust stereo vision based drivable road detection and tracking system is developed based on Markov to navigate intelligent vehicles through challenging traffic conditions. The current schemes in the aforementioned literature commonly use Markov Model as an approach for prediction purposes in vehicular networks. Therefore, our approach revolves around Markov model to predict the next anticipated TDRR for priorities classification purposes.

Analytical and simulated models have been extensively utilized to verify VANET schemes. In [13] an analytical model for average delay which is built based on a new mobility model is introduced to increase system reliability. The proposed model is validated by means of simulation using realistic vehicular traces. Subsequently, [14] addresses the importance of timely and reliable message delivery in VANET and presented a mathematical framework for message delivery delay for a two-lane road. On the other hand, in [4], an analytical model is developed to analyze safety message dissemination in vehicular ad hoc networks specifically for two priority classes, high priority and low priority. In [15], to develop a fully dynamic service VANET schemes with the goals of maximizing the total user-satisfaction and achieving a certain amount of fairness, analytical model is used to define the media service as an optimization problem with a joint content dissemination and cache update scheme. The optimization problem formulated is to ensure fairness. Based on the current schemes thus far, analytical model for efficient scheduling with the objective to ensure delivery of emergency messages with the use of five priorities classes have not been developed. An analytical analysis approach has been conducted to model the five priority classes in MarPVS.

Research efforts on VANET protocols focus mainly in ensuring packet transmissions efficiency amongst the default four priorities classes. However, accidents are prone when vehicles are in close proximity. In addition, we observed that delivery success rate increases and queuing delay decreases when transmission prioritizes packets between vehicles in close TDRR as compared to vehicles located far from each another. Thus, if we prioritize close TDRR transmission, bandwidth utilization efficiency can be increased. In addition, failed data transmission that hoards the bandwidth and increases delay for other traffics which usually occurs between vehicles located far from each other can be reduced as well. Therefore, our emphasis is to increase the overall transmission efficiency in VANET by prioritizing communications between vehicles in close proximity.

3. The Proposed Markov TDRRPrediction with Enhanced Priority VANET Scheme (MarPVS)

In this section, we discuss the proposed MarPVS. In MarPVS, we propose five priority levels. The highest priority level is used to cater for the highest priority emergency messages between short TDRR vehicles. In addition, in MarPVS, all short TDRR transmissions' priorities are increased by one level as compared to the default IEEE802.11p four priorities EDCA. The proposed MarPVS is discussed in detailed in the following sections. In section 3.1, Markov model is developed to perform TDRR prediction. TDRR predicted is used to determine the priority levels in section 3.2. In section 3.3, we discuss the proposed MarPVS priority scheme allocated based on data type and TDRR predicted in section 3.1. In section 3.4, we perform an analytical analysis and derived the delay mathematical expressions for the proposed MarPVS. To the best of our knowledge, no existing delay mathematical expression for five priorities VANET scheme based on TDRR prediction has been derived to address the reliability in terms of delay for the emergency messages.

3.1 The Proposed MarPVS Markov Model TDRR Prediction

Path loss model for VANET subjects to loss due to mobility and surrounding interference. Therefore, in our proposed model, TDRR is calculated based on a path loss formula derived for VANET applications as discussed in [8] and [14], **Table 1**, shown in equation (1). VANET path loss model is then used to compute TDRR which addresses VANET path loss components.

$$Path\ Loss, PL(d) = PL(do) + 10nlog\left(\frac{d}{do}\right) + X_{\sigma 2} + \zeta PL_C \qquad (1)$$

where

PL(do) denotes the path loss at a reference
reference TDRR $d_0=10m$
n denotes the path loss exponent
$PL_c$is a correction term that accounts for the offset between forward and reverse path loss
$X_{\sigma 2}$ is a zero-mean normally distributed random variable with standard deviation σ_1
ζ is defined as 1 for reverse path loss [16]

Table 1. Model Parameters in [16]and [17]

Scenario	PL(do) (dB)	n	σ_1 (dB)	PL_c (dB)
Highway	63.3	1.77	3.1	3.3
Urban	62.0	1.68	1.7	1.5
Suburban	64.6	1.59	2.2	N/A

$$Distance\ (TDDR), d = d_o * \ antilog\left(\frac{PL(d) - PL_0 - X_{\sigma 2} - \zeta PL_C}{10n}\right) \qquad (2)$$

TDRR between communicating nodes is derived in equation (2) based on equation (1) where TDRR between communicating vehicles is predicted using Markov model. Transition probabilities are calculated based on history data whereas TDRR is predicted using Markov model, as shown in **Fig. 1** below. A high TDDR is desired for successful packet transmission. Due to varying nature of VANET environment, interference varies and fluctuates. To ensure successful and reliable transmission, TDDR 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. In the following section, the usage of near represents high transmission reliability whereas far represents low transmission reliability.

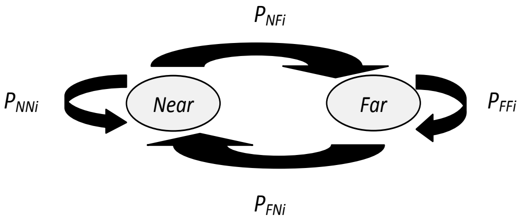
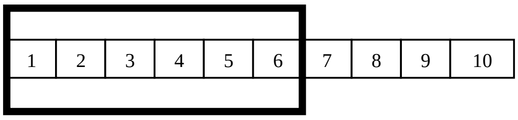
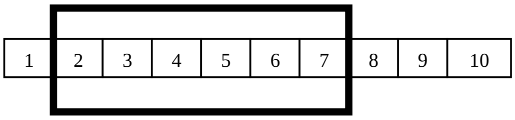


Fig. 1. Proposed Markov Chain

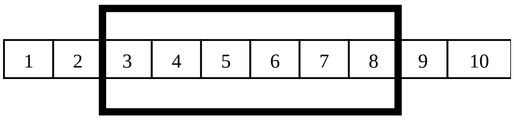
Probabilities shown in **Fig. 1** are calculated based on equations (3)-(6) where data are first collected for an interval of i_{th} times. A sliding window is formed using i_{th} interval to ensure data collected are consecutively updated as shown in **Fig. 2**. Based on data recorded, probability of near-far transition (P_{NFi}) , probability of far-far transition (P_{FFi}) , probability of far-near transition (P_{FNi}) and probability of near-near transition (P_{NNi}) are derived based on equations (3)-(6). T_{NF} represents the total number of near-far transition in the interval of i_{th} times whereas T_{FN} represents the total number of far-near transition in the interval of i_{th} times. S_N represents the total number of near occurrence and S_F represents the total number of far occurrence in the interval of i_{th} times.



First interval, where six consecutive distance range are monitored



Second interval, where another six consecutive distance range are monitored



Third interval, where another six consecutive distance range are monitored

Fig. 2. Proposed Timing Chart of a Sliding Window where i=6

$$Probability\ of\ Near-Far\ Transition, P_{NFi} = \frac{T_{NFi}}{S_{Ni}} \text{ where } i > 0 \tag{3}$$

$$Probability\ of\ Far-Far\ Transition, P_{FFi} = 1 - \frac{T_{NFi}}{S_{Ni}} \text{ where } i > 0 \tag{4}$$

$$Probability\ of\ Far-Near\ Transition, P_{FNi} = \frac{T_{FNi}}{S_{Fi}} \text{ where } i > 0 \tag{5}$$

$$Probability\ of\ Near-Near\ Transition, P_{NNi} = 1 - \frac{T_{FNi}}{S_{Fi}} \text{ where } i > 0 \tag{6}$$

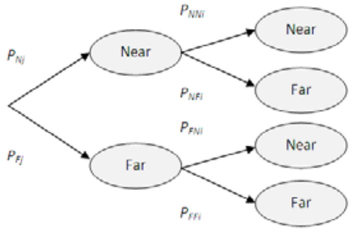


Fig. 3. Proposed Transmission Distance Reliability Range(TDRR) Prediction using Calculated Probabilities in Markov Model

The final TDRR prediction using Markov model is calculated based on **Fig. 3** where probability of near occurrence (P_{Nj}) is derived based on equation (7) and probability of far occurrence (P_{Fj}) is derived based on equation (8). T_{Nj}represents the total number of near occurrence within thej_{th} interval, T_{Fj} represents the total number of far occurrence within the j_{th} interval and S_{Sj} represents the total sum of near and far occurrence.

$$Probability\ of\ Near\ Occurence, P_{Nj} = \frac{T_{Nj}}{S_{Sj}} \text{ where } j > 0 \tag{7}$$

$$Probability\ of\ Far\ Occurence, P_{Fj} = \frac{T_{Fj}}{S_{Sj}} \text{ where } j > 0 \tag{8}$$

The final probability of TDRR prediction is derived based on equations (9) and (10). $FP_{Near}$is compared with FP_{Far} where the higher probability indicates the next predicted range of TDRR between communicating vehicles. In the simulation, probabilities stated in the MarPVS Markov Model are obtained every 0.1 seconds and it is only considered near if the range between cars is within 50 metres. If the final probabilities of near and far are the same, MarPVS increases its window size by 1. If the same probabilities between near and far are obtained again, MarPVS assigns the transmission as near transmission. This is because in order to obtain more than one near transmissions within 0.6 seconds, it could mean that the car is still within (or at the edge) of the range. However, for the same near and far probabilities to be obtained, the cars have to drive within the range of near and far, near and far consecutively for 0.6 seconds which is quite impossible to occur. Normally, cars stay within range and only move out of the range within 1- 60 seconds [2]. The transitions between near and far however can be immediately captured with the measurement of Markov model in MarPVS at every 0.1seconds. Thus, to ensure efficient Markov Model in MarPVS, the interval where transitions are recorded should be set to be less than 1s.

$$Final\ Probability\ of\ Near\ Occurence, FP_{Near} = \left(P_{Nj} * P_{NNi}\right) + \left(P_{Fj} * P_{FNi}\right) \tag{9}$$

$$Final\ Probability\ of\ Far\ Occurence, FP_{Far} = \left(P_{Nj} * P_{NFi}\right) + \left(P_{Fj} * P_{FFi}\right) \tag{10}$$

3.2 The Proposed MarPVS Priority Scheme

The default IEEE802.11p uses EDCA MAC protocol operation defined in IEEE802.11e which prioritizes data transmission according to four different priorities assigned solely based on data type [6].

However, in VANET, accidents are prone when vehicles are in close distance, hence TDRR is used in MarPVS as one of the criteria to determine priority levels. In this paper, five classes of message traffics priorities of MarPVS are developed based on TDRR and data type as shown in tables 2 and 3. The first priority level is the lowest priority traffic categorized as data type Access Priority Background, AC_BK with furthest TDRR from the source node. The second priority level consists of data type Access Priority Best Effort, AC_BE with TDRR categorized as far to the source node and data type AC_BK with TDRR categorized as near to the source node. The third priority level consists of data type Access Priority Video, AC_VI with TDRR categorized as far from the source node and data type AC_BE with TDRR categorized as near to the source node. The fourth priority level consists of data type Access Priority Voice, AC_VO with TDRR categorized as far from the source node and data type AC_VI with TDRR categorized as near. The fifth priority level is the highest priority amongst all where data type, AC_VO with TDRR categorized as near, transmitting emergency safety messages are given the highest priority, Access Priority Special, AC_SP to transmit its packets.

Priorities are assigned based on its contention window. A longer contention window means the packet has to wait longer for its turn to transmit whereas a short contention window allows packets to have better transmission opportunity since the queuing delay is shorter. In **Table 2**, the proposed MarPVS priority scheme with assigned contention window is presented where the shortest contention window is assigned for priority level 5, AC_SP. When TDRR between vehicles is near, in **Table 3**, we observed that the default IEEE802.11p traffics' priorities are upgraded by one level in MarPVS priority scheme.

Table 2. Proposed MarPVS Priority Scheme

	Priority Levels	Designation	MarPVS CWmin	MarPVSCWmax
High	5	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
Low	1	AC_BK	aCWmin	aCWmax

Table 3. Proposed MarPVS Priority Assignment according to TDRR and Traffic Type

No	IEEE802.11p Traffic Data Type (Designation)	MarPVS TDRR	MarPVS Priority (Designation)
1	AC_VO	Near	AC_SP
2	AC_VO	Far	AC_VO
3	AC_VI	Near	AC_VO
4	AC_VI	Far	AC_VI
5	AC_BE	Near	AC_VI
6	AC_BE	Far	AC_BE
7	AC_BK	Near	AC_BE
8	AC_BK	Far	AC_BK

3.3 The Proposed MarPVS Algorithm

In MarPVS, an enhanced priority scheme based on TDRR and data type is proposed to ensure safety messages in near TDRR has higher reliability in reaching its destination node in time. Accidents are prone to happen when vehicles are in near distance. Therefore, safety packet transmissions with TDRR categorized as near are given the highest priority in MarPVS. Detailed MarPVS algorithm is explained with a pseudo code in **Fig. 4**. In algorithm 1, TDRR between communicating vehicles are computed based on equation (12). A sliding window *i* is applied to collect consecutive TDRR for Markov model. TDRR obtained from communicating vehicles is categorized as near or far based on threshold *r*. Markov probabilities are then updated and calculated based on equations (3)-(8). The final probabilities FP_{Near} and $FP_{Far}$are calculated based on equations (9)-(10). Based on previous data collected, future TDRR prediction of the vehicle is obtained based on final probability of occurrence calculated in *FP*. FP_{Near} is compared with $\mathrm{FP}_{\mathrm{Far}}$ where the higher probability indicates the next predicted range of TDRR between communicating vehicles.

In algorithm 2, if the predicted TDRR between communicating vehicles is near and type of data transmitted is of high priority, the packet is categorized as priority level 5. For the rest of the data traffics, if the predicted TDRR is near, priority level is increased by one level. These transmitted packets are assigned with less contention window in the priority scheme if the predicted TDRR is near in order to reduce overall queuing and transmission time and increase probability of successful transmission. Since accidents usually occur within short distance range, therefore, emergency messages with near TDRR is treated as the highest priority to ensure drivers are well informed of its surrounding to prevent mishaps.

```
Input: Transmitted and Received Power
Output: TDRR, Priority
While ("messages are received") do
Algorithm 1: TDRR Prediction
  foreach Time do
    Calculate TDRR based equation (2).
    If TDRR<r, record as Near
    else if TDRR>r, record as Far
    Update $T_{NFi}, T_{FFi}, T_{NNi}, T_{FNi}, S_{Ni}, S_{Fi}, T_{Nj}, T_{Fj}, S_{Sj}.$
    Calculate $P_{NNi}, P_{FFi}, P_{NFi}, P_{FNi}, P_{Nj}, P_{Fj}$based on equations (3)-(6).
    Using Markov model, compute $FP_{Near}$and $FP_{Far}$based on equations (7)-(8).
    If $FP_{Near} \geq FP_{Far}$ update TDRR = Near
    else if $FP_{Far} \geq FP_{Near}$ update TDRR = Far
    end
  end
end Algorithm 2: Assignment of Priority
  foreach Time do
    If ((TDRR==Near)&&(priority==AC_VO)),  newpriority = AC_SP
    else If ((TDRR==Near)&&(priority==AC_VI)),  newpriority = AC_VO
    else If ((TDRR==Near)&&(priority==AC_BE)),  newpriority = AC_VI
    else If ((TDRR==Near)&&(priority==AC_BK)),  newpriority = AC_BE
    else newpriority = priority
    end
  end
```

Fig. 4. Proposed MarPVS Pseudo code

3.4 MarPVS Analytical Model

In this section, we develop analytical delay model for each priority defined in MarPVS. To compute the probability of successful packet transmission based on priority, we assume worst case scenario where maximum contention window arises. In scenarios where maximum contention window takes place, we define the minimum number of packets transmission within a defined period of time. Based on the minimum number of packet transmission, probability of successful packet transmission for each priority defined in MarPVS can be derived. Each node can have at most one message per transmission and no other nodes can transmit when an ongoing transmission is detected. Transmission time for all traffic classes are exponentially distributed with parameter µ. Nodes are assumed to be entering the highway according to a Poisson process with parameter Φ nodes per unit length of the highway.

We assume that within a time frame of έ seconds, transmission is reserved for a single priority type. Therefore, within 5έ seconds, five different priority levels traffics are transmitted within 5έ seconds where only one priority transmission is allowed to take place within έ seconds. For each priority transmission, we assume worst case scenario where maximum contention window size takes place. Maximum transmission time for one packet in each priority level, g_ρ is then calculated in equation (11) based on carrier sense multiple access, CSMA distribution of slots shown in **Fig. 5**.

AIFSN	CW	SIFS	FRAME	AIFSN	CW	SIFS	FRAME

Fig. 5. MAC CSMA

$$g_\rho = AIFSN_\rho + CW_\rho + SIFS_\rho + FRAME \tag{11}$$

Once the maximum transmission time for a single packet transmission in each priority, g_ρ is calculated, minimum number of packets transmitted for each priority within the maximum contention window size, φ_ρ can be derived by dividing a constant period of time defined by the maximum transmission time for the lowest priority data type with the maximum transmission time for one packet in for each priority as shown in equation (12).

$$\varphi_\rho = \frac{\acute{\varepsilon}}{g_p} \tag{12}$$

By substituting equation (11) and equation (12) into equation (13), we obtain the probability of successful packet transmission in each priority. With $\overline{P}_\rho$, probability of packets with different priority levels in MarPVS contenting for a transmission opportunity can be derived in equation (13).

$$\overline{P}_\rho = \frac{\varphi_\rho}{\sum_{\rho=1}^{\rho=5} \varphi_\rho} \tag{13}$$

High priority traffics are always given the privilege to transmit first. Hence, transmission of low priority traffic when high priority traffics transmission occur results in a back off process. Let us define a congested channel where continuous transmissions are active. Nodes' transmission priority is defined by TDRR and data type in MarPVS. For different priority level, transmission has different transmission opportunity. When a priority level 5 transmission occur, the rest of the priority levels have to schedule their back off counters. Thus, the number of low priority messages in the back off process, k_ρ is derived with the assumption that only one transmission is allowed to take place between two communicating nodes. Hence, probability of low priority transmission occurs when transmission of high priority takes place is derived in equation (14).

$$k_{\rho} = \frac{\Phi}{2} \sum_{\rho=1}^{\rho-1} \varphi_{\rho} \sum_{\rho}^{\rho=5} \varphi_{\rho} \tag{14}$$

Therefore, number of concurrent low priority transmission, n_{ρ} is derived in equation (15).

$$n_{\rho} = \frac{\Phi}{2} \sum_{\rho=1}^{\rho-1} \varphi_{\rho} \tag{15}$$

Average packet transmission time, μ_{ρ} for each priority level defined in MarPVS is computed based on the total transmission time needed for a transmission to be delivered from the source node to the destination node. The calculation includes processing delay, propagation delay, transmission delay and queuing delay. Average packet transmission time, μ_{ρ} is derived in equation (16)

$$\mu_{\rho} = \frac{L}{C} + \frac{d}{v} + \frac{\varsigma}{\mu - \lambda} + \gamma_{\rho} \tag{16}$$

where$L$ = average packet length, C = link transmission capacity, d = TDRR , v = propagation speed, λ = arrival rate, $\varsigma = \lambda/\mu$, $\mu = C/L$ and γ = priority queuing delay.

Probability for lower priority transmissions to be queued when it reaches its destination node is higher, thus, priority queuing delay for each priority level is defined in equation (17). Assume that only a one to one communication can take place at a time, priority queuing delay, $\gamma_{\rho} = \delta$ is derived in equation (17)

$$\gamma_{\rho} = (AIFSN_{\rho} + CW_{\rho} + SIFS_{\rho}) \frac{\Phi d}{2R} \tag{17}$$

where$R$ = total highway length, d= current transmission range, δ = time for each slot, $AIFSN_{\rho}$ = number of $AIFSN$ slot for ρ priority, CW_{ρ} = number of contention window slot for ρ priority, $SIFS_{\rho}$ = number of SIFS slots for ρ priority and Φ = total number of vehicles.

In [5], average number of activity regions is defined only for only two priority levels. In MarPVS, we computed five defined priority levels and based on [5], the average number of activity regions with number of concurrent low priority transmission with priority ρ and n_{ρ}concurrent transmission is defined as,$\overline{m}\ (n_{\rho} = \sum_{m=1}^{n_{\rho}} mQ_m(n_{\rho})$ where $Q_m(n_{\rho})$ is the probability distribution function of the number of activity regions with n_{ρ} concurrent transmission. Average length of the sum of the activity regions with n_{ρ} concurrent transmission derived using MarPVS is therefore defined in equation (18).

$$l(n_{\rho}) = \begin{cases} [2\overline{m}(n_{\rho}) + (0.5P_c + 1.5P_h)(n - \overline{m}(n_{\rho}))]d & \text{if } n_{\rho} > 0 \\ 0, & \text{if } n_{\rho} = 0 \end{cases} \tag{18}$$

Average sum of interference sub regions with n_{ρ}concurrent transmission derived using MarPVS is thus defined in equation (19)

$$h(n_\rho) = \begin{cases} (1.5P_c + 0.5P_h)(n - \bar{m}(n_\rho))]\mathrm{d} & \text{if } n_\rho > 0 \\ 0 & \text{if } n_\rho = 0 \end{cases} \tag{19}$$

whereP_c and P_h denote the probabilities of internal and external interferences respectively based on [5]. After further manipulations, the birth rate of number of concurrent transmission when state of system in (n_ρ, k_ρ), with priority defined by MarPVS is computed in equation (20),

$$\alpha_{n_{\rho|}k_\rho}(n_\rho) = \lambda_\rho \left(\Phi - \frac{k_\rho}{R}\right)\left(R - l(n_\rho)\right) + \frac{k_\rho\beta}{R}(R - l(n_\rho)) \tag{20}$$

Next we denote the death rate of number of concurrent transmission when state of system is in (n_ρ, k_ρ), with priority defined by MarPVS in equation (21)

$$b_{n_{\rho|}k_\rho}(n_\rho) = n_\rho \bar{\mu}_\rho \tag{21}$$

whereλ_ρ = Poisson arrival rate for different priority level, $\beta = \frac{1}{\alpha\omega_\rho}$, α = backoff time slot , ω_ρ = backoff contention window size for different traffic class, $\bar{\mu}_\rho$ = transmission time of a message for different traffic classes is exponentially distributed with parameter $\bar{\mu}_\rho$. Operating with exponential arrival rates, we can model the Markovian birth-death process in [5]with MarPVS different priority level in equation (22).

$$(n_\rho|k_\rho) = \text{þ}_{0|k_\rho} \prod_{i=0}^{n_p} \frac{a_{i|k(i)}}{b_{i+1|n_\rho(i+1)}} \qquad 0 \le n_\rho \le n_{\rho\,max} \tag{22}$$

Probability that no new low-priority transmission starts in the transmission range of a forwarding node within a time slot, α is derived in equation (23).

$$P_s(n_\rho, k_\rho) = e^{-\Gamma_{n_\rho,k_\rho}\alpha} \tag{23}$$

Unconditional probability of $P_s(n_\rho, k_\rho)$ that within a time slot α, no new low priority transmission starts in a transmission range of a forwarding node for different priority level in MarPVS is derived in equation (24).

$$P_{s(\rho)} = \sum_{k_\rho=0}^{n_\rho\,max} \sum_{n_\rho=0}^{n_\rho\,max} e^{-\Gamma_{n_\rho,k_\rho}\alpha}\, \text{ρ}_{n_{\rho|}k_\rho}(n_\rho|k_\rho) \tag{24}$$

If the medium is free and the node proceeds with transmission of packets, the forwarding delay is $\alpha + \bar{x}_\rho$. On the other hand, if the medium is busy and it defers the transmission after completion of an ongoing transmission and a back off process, the forwarding delay becomes $0.5\alpha + \bar{x}_\rho + E_\rho[backoff\ time\,] + \bar{x}_\rho$. As the consequence of a single back off procedure in the broadcasting mode, the average delay experienced by the i^{th} forwarding node in each priority level defined in MarPVS is given in equation (25)

$$\bar{d}_{h(\rho)} = P_{s(\rho)}(\alpha + \bar{x}_\rho) + (1 - P_{s(\rho)})(0.5\alpha + \bar{x}_\rho + E_\rho[backoff\ time\,] + \bar{x}_\rho) \tag{25}$$

where the slot is randomly selected, E_ρ[backoff time] = $\frac{\omega_\rho}{2} T_{st(\rho)}$ and $\bar{x}_\rho = \mathcal{E}_\rho e^{-d\mu_\rho} - \mathcal{E}_\rho$, $\varepsilon\mathcal{E}_\rho = \frac{\varsigma}{\mu-\lambda}(\frac{1}{\bar{b}}\bar{P}_\rho)$ and $\bar{b} < 1$.

Since a low priority transmission may start with probability $1 - P_{s(\rho)}$ within a slot duration, the average waiting time for each counted slot shown by forwarding delay for each priority level in MarPVS is derived in equation (26).

$$T_{st(p)} = P_{s(\rho)}\alpha + \left(1 - P_{s(\rho)}\right)(0.5\alpha + \bar{x}_\rho + T_{st(\rho)}) \tag{26}$$

When a source node generates a high priority message, it may be located in an activity region [5]. Thus, probability of such event is derived as $P_{i(\rho)}$ in equation (27).

$$P_{i(\rho)} = \sum_{j=1}^{n_\rho\, max} h_\rho(j)/l_\rho(j)p_{n_\rho}(j) \tag{27}$$

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 equation (24). The overall average transmission delay for each MarPVS priority level is derived in equation (28).

$$\bar{D}_\rho = P_{i(\rho)}[\frac{\omega_\rho}{2} T_{st(\rho)} + 1.5\bar{x}_\rho] + \left(1 - P_{i(\rho)}\right)\bar{d}_{h(\rho)} \tag{28}$$

4. Simulation and Analysis

In this section, we present the numerical results with regards to the performance modeling analysis presented in the previous sections, as well as simulation results to confirm the accuracy of the analysis. An event driven platform was developed using MATLAB software to perform the analytical analysis of MarPVS whereas simulation was performed using real life map in the urban city of Kuala Lumpur, Malaysia shown in **Fig. 6**, [18] with Omnet-4.2.2 with Vehicles Network Simulation (Veins) with Simulation of Urban Mobility, SUMO and open google map application are used as the simulation software [19]. Simulation was performed in an urban mobility pattern where there are two ways traffic flows, traffic lights and cars moving in every 3 seconds. We performed multiple independent simulations where statistics were collected after the system has reached steady state. Simulation was performed with the assumption that transmissions are sent without request to transmit (rts), clear to transmit (cts) and acknowledgement (ack) packets since the objective of VANET is to successfully deliver emergency messages within the stipulated time frame and the introduction of cts/rts/ack increases delay and packet drops which defeats the purpose of VANET [20, 21]. Parameters used for the simulation is explained in **Table 4** Time for each slot, δ, and contention window size are selected based on the VANET standard as defined in [13] and [22].

Fig. 6. Kuala Lumpur, Malaysia city centre map (Urban Area)

Table 4. Traffic Parameters

Parameter	Value
Packet arrival rate, λ	0.05s
Number of vehicles, Φ	30 - 150
Packet size	512 bytes
Transmitted power	19 dBm
Time for each slot, δ	0.000013s
Interval, i	6
Interval, j	6
Threshold, r	50 metres
Number of events, ň	62,500

The accuracy of the proposed TDRR prediction with Markov model is shown in **Fig. 7** Analytical and simulation results for predicted TDRR are compared and the percentage of difference between near and far occurrences are plotted in **Fig. 7** The analytical and simulation results are shown to be closely similar and above 95% accuracy which shows the reliability of the proposed TDRR prediction using Markov model. Markov model is used to predict future TDRR based on previous data collected. As such a slight drop is noticed in the beginning of time. However, an average of above 95% accuracy is still achieved. The high accuracy of TDRR prediction ensures priorities for data traffics are allocated accordingly to ensure transmission efficiency and reliability.

Table 5. Complexity Measurement

	Run Time (seconds)	**Percentage of Increased Run Time (%)**
Default IEEE802.11p Scheme	25.8641	-
Reference Scheme in [7]	25.9531	0.3441%
MarPVS	25.9092	0.1744%

We compared the complexity of the proposed MarPVS with the default IEEE802.11p scheme and reference scheme in [7] with the use of simulations. Complexity of the three schemes is measured with run time and ň number of events with the use of Microsoft Windows 8 platform, Intel Core I3 Processor and 4 GB RAM. In Table 5, the proposed MarPVS shows low complexity with lower percentage of increased run time.

Fig. 8 and **9** show the effects of parameter *r* selection on MarPVS simulation where a reduction of packet success rate and increase of delay are observed when parameter threshold r increases. When threshold *r* increases, the range of emergency packets communication increases, thus an increment of packets categorized as near transmission increases. These packet are given higher priority which results in performance similar to the default IEEE802.11p. Therefore, a low r threshold should be set to ensure efficient scheduling. Afterall, information between near VANET nodes are inherently more important because information on roads further from the cars' locations is deemed redundant as there might have been a change of traffics even before the car reaches near the location itself.

Fig. 10 to **19** present the analytical and simulated results for analytical MarPVS, simulated MarPVS, default IEEE802.11p scheme and reference scheme in [7]. As can be seen from the figures, when the number of vehicles increases throughout a period of time, channel congestion increases which results in high transmission delay. With the proposed MarPVS, vehicles within close TDRR are permitted to transmit with higher priority which results in overall shorter queuing delay. Transmissions between vehicles with increased TDRR are usually prone to interference and packet drops. Thus, if transmission is prioritized solely based on data type as stated in the default IEEE802.11p scheme, transmission between vehicles with increased TDRR causes wastage of transmission opportunity because longer distance packetsare prone to delay and interference. Subsequently, if transmission is prioritized based on data type and time restriction of packets as discussed in reference scheme in [7], starvation in lower priority queues becomes prone as shown in reference scheme [7] in **Fig. 14** and **19**. It can be observed in reference scheme [7] that transmission of packets with different time restrictions entering the queue and contesting for opportunity to transmit without any gradual indications causes intense competition and results in inefficient throughput and delay. However, if we prioritize transmission of packets between shorter TDRR vehicles and data type as proposed in MarPVS, packets have higher success rate due to predictable TDRR and efficient bandwidth scheduling. This is because near TDRR transmissions are prioritized and farTDRR transmissions that are prone to interference and packet drops which hoards the bandwidth inquiring high delay is reduced, consequently reducing the overall queue buffer and waiting period. With shorter queuing delay and efficient bandwidth scheduling, MarPVS improves the overall transmission delay and packet success rate. With lower delay, transmission time is less due to less queuing time. Packets are dropped when it exists time to live (TTL). As such, with lower delay, packets are transmitted within the TTL period. Thus, packet reaches destination node on time. Reduced average transmission delay contributes to higher packet success rate. Therefore, as can be seen in **Fig. 10** to **14** the overall MarPVS packet success rate increases whereas delay decreases as compared to the default IEEE802.11p scheme and reference scheme in [7]. It can also be observed that with proper scheduling, where we prioritize near transmission in MarPVS, queuing delay is reduced. As such, multi-hops transmissions are reduced. This is because MarPVS prioritises near transmission where multi-hops transmission eventually resorts to transmit to nearer nodes and the transmission becomes single-hop which reduces the delay and improves packet success rate.

A lower bound average delay which represents the minimum average delay of packet transmission is plotted as the analytical MarPVS modeling based on analytical expressions which are discussed in the previous sections. Based on the probability of successful packet transmissions calculated for all MarPVS priority levels, we computed the number of low priority messages in backoff process, the number of concurrent low priority transmission and average packet transmission time for analytical MarPVS. Finally, the results are used to derive the average transmission delay for different data types defined in analytical MarPVS. We observed a good agreement between numerical and simulation results as shown in **Fig. 15** to 19. Numerical results and simulation results confirm the accuracy of the proposed analysis. Results show that in VANET high nodes density and mobility networks, distribution of packets prioritized according to TDRR and data type achieve better optimization and adaptation of contention window and improve transmission latency.

The overall packet success rate is higher in the proposed MarPVS as compared to the existing default IEEE802.11p scheme and reference scheme in [7]. This is because higher priority is given to packet transmission between close TDRR vehicles which is usually less affected by interference and noise as compared to packet transmission between far TDRR vehicles. Thus, with higher priority given to vehicles communicating in close TDRR, shorter transmission delay is observed due to less propagation time and queuing delay. With reduced transmission time, bandwidth utilization efficiency and overall packet transmission waiting and queuing time are improved. The proposed MarPVS is shown to be able to reduce average delay and increase packet success rate of packet transmissions in VANET.

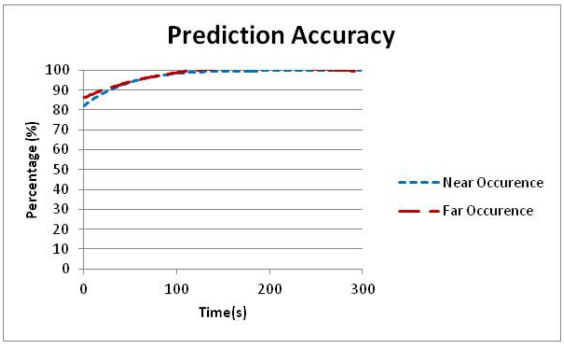


Fig. 7. Markov Prediction Validation

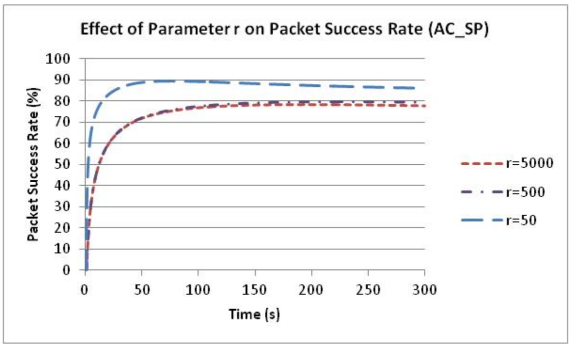


Fig. 8. Effect of Parameter r on Packet Success Rate (AC_SP)

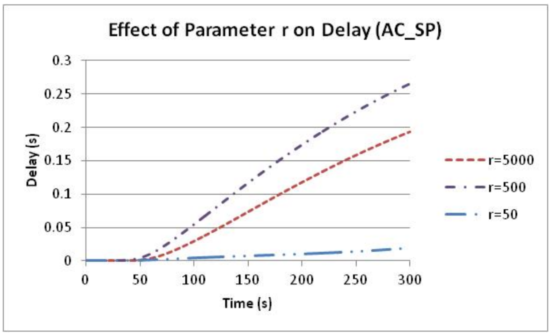


Fig. 9. Effect of Parameter r on Delay (AC_SP)

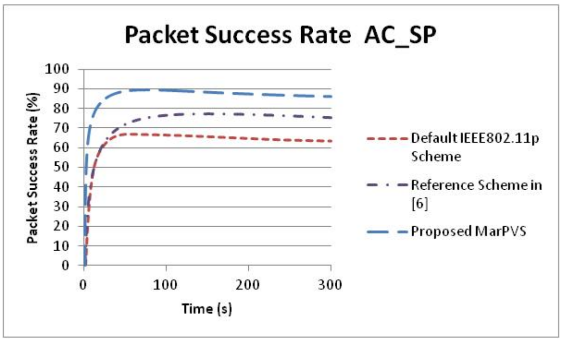


Fig. 10. Packet success rate AC_SP

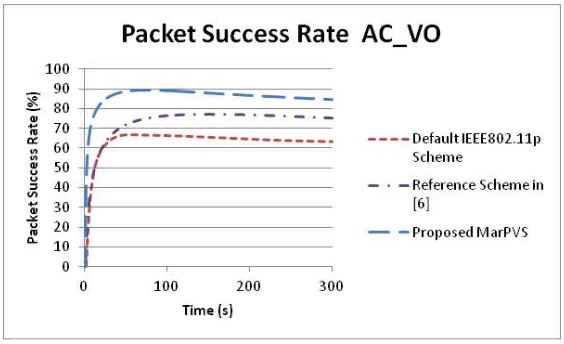


Fig. 11. Packet Success Rate AC_VO

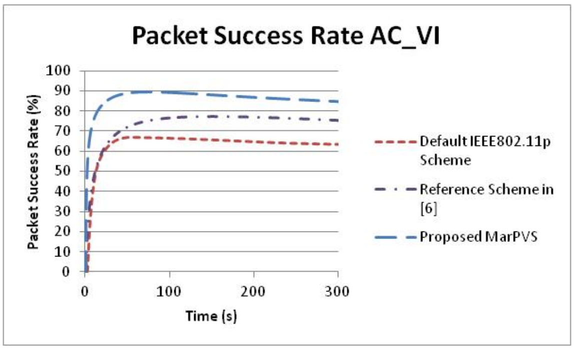


Fig. 12. Packet Success Rate AC_VI

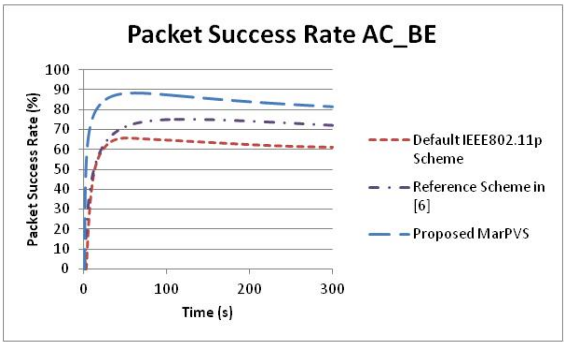


Fig. 13. Packet Success Rate AC_BE

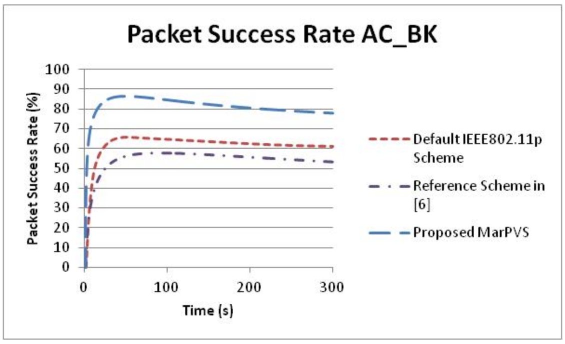


Fig. 14. Packet Success Rate AC_BK

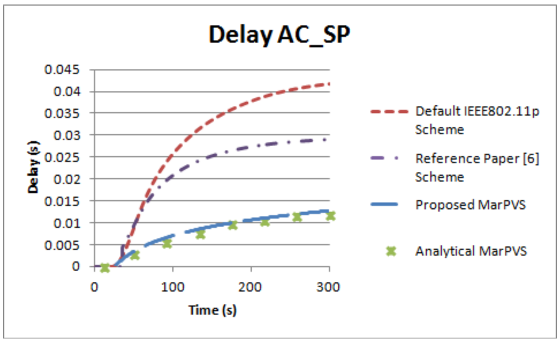


Fig. 15. Average Delay AC_SP

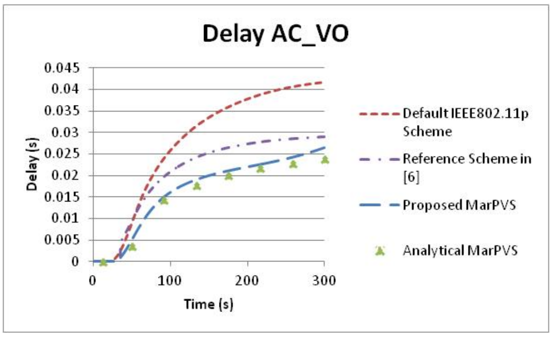


Fig. 16. Average Delay (AC_VO)

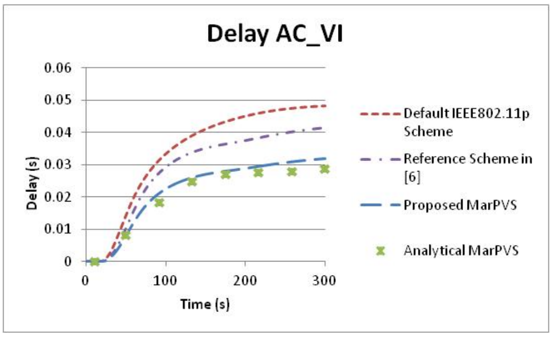


Fig. 17. Average Delay (AC_VI)

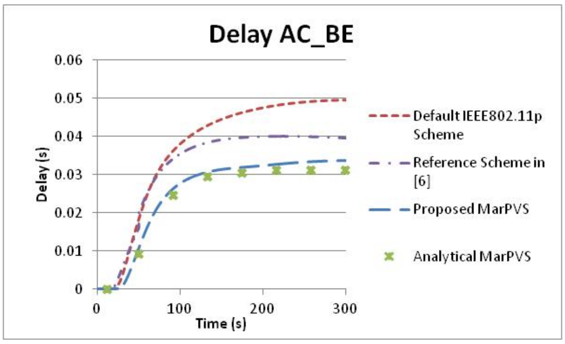


Fig. 18. Average Delay (AC_BE)

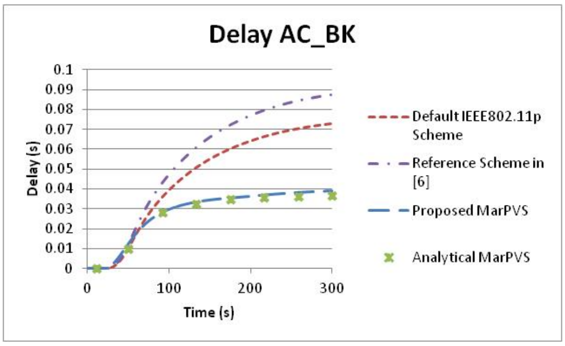


Fig. 19. Average Delay (AC_BK)

5. Conclusion

VANET topology is prone to unpredictable environment and interference. Hence, priorities based on data type and TDRR in MarPVS is important to ensure optimized performance and adaptable nodes. In this work, we proposed a Markov model based priority scheme which predicts future TDRR between communicating vehicles. Since vehicles in VANET are highly mobile, priorities assigned during transmission would have been obsolete upon reaching its destination node. As such, we used Markov model to predict the future TDRR between communicating vehicles based on past TDRR data obtained. Based on the predicted TDRR and type of data, we proposed a new Markov TDRR Prediction with Enhanced Priority VANET Scheme (MarPVS) where priorities are classified according to data type and TDRR between vehicles. With priorities given to close TDRR vehicles, bandwidth utilization can be improved and thus, increases packet success rate and decreases average delay. The performance modeling of MarPVS is derived in this paper to confirm the simulation results. In the analytical analysis, we first explained the MarPVS algorithm and then we derived the number of low priority messages in the back off process, number of concurrent low priority transmission and average packet transmission time for MarPVS. Then, based on Markov Birth death process and average forwarding delay, we derived the average transmission delay for different data types defined in MarPVS. Numerical results are provided along with simulation results which confirm the accuracy of the proposed analysis. Results show that in VANET high nodes density and high mobility networks, distribution of packets prioritized according to TDRR and data type improve transmission latency and packet success rate.

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