

Chapter 2

Adaptive Connectivity for Vehicular Cyber-Physical Systems

2.1 Overview

Vehicular connectivity is regarded as a backbone for communications in intelligent vehicular CPS to provide timely information to drivers or to provide feedback to the vehicles on the road to enhance road safety and overall traffic efficiency. Note that about “60 % of roadway collisions could be avoided if the operator of the vehicle was provided warning at least one-half second prior to a collision” [1, 2]. When vehicles use fixed transmit range/power for communications, they may not be able to connect with their neighboring vehicles using single hop or multiple hops in case of sparse vehicle density. At the same time, when high and fix transmission range/power is used, there could be broadcast storm problem because of rebroadcast of the messages from several vehicles within the given transmission range. Thus, individual vehicles should be able to adapt their communication parameters including transmission power/range based on their corresponding local observations without any intervention from driver/users [3]. Furthermore, quick data transmission is essential for emergency related messages in vehicular networks to disseminate them in a timely manner [4–9] using vehicle-to-vehicle and/or a vehicle-to-roadside-to-vehicle communications. When all messages in vehicular CPS are treated equally, time sensitive emergency messages could face higher delay in case of saturated network and drivers/vehicles could not be informed in a timely manner. Thus message differentiation becomes a vital factor for providing means to disseminate time sensitive emergency messages in the network rather quickly. Note that when there is no priority for emergency messages, they could suffer from delays and they would have no purpose after certain time.

This chapter investigates an analytical approach for enhancing network performance through dynamic adaptation of transmit power and contention window in vehicular CPS. Transmission range/power is adapted based on both local traffic density and data collision rate in the network. Furthermore, contention window sizes of differentiated messages is adapted based on the data collision rate in the

network. Note that the smaller the contention window for the message, faster it gets the transmission opportunity.

Performance is evaluated using numerical results obtained from simulations by considering different metrics such as transmission range, throughput, delay, and CW size.

2.2 Adaptive Transmission Range/Power

In VANETs, each vehicle is required to broadcast its status such as position, speed, and direction periodically (approx. 10 times every second) to other vehicles. Thus, it is assumed that all vehicles have access to periodic status data about real-time locations of their surrounding vehicles. This information can be used to estimate number of neighboring vehicles on the road. Furthermore, this estimated number can be used to find local vehicle density for a given vehicle. The local vehicle density (δ) can be calculated as the ratio of the actual number of vehicles on the road N_0 and the total possible number of vehicles on the road N_p for a given transmission range as shown in Fig. 2.1. For example, for 2 lane road with vehicles maintaining 10m safety separation distance and having 500m (diameter) transmission range, the total number of possible vehicles $N_p = 2 \times 500/10 = 100$ as in Fig. 2.1a. The local vehicle density can be expressed as

$$\delta = \frac{N_0}{N_p} \quad (2.1)$$

Furthermore, each vehicle can estimate the occurrence of data collision in the network for each message category $m = 0, 1, 2$ and 3 as

$$P_c = \frac{1}{4} \sum_{m=0}^3 P_c^m = \frac{1}{4} \sum_{m=0}^3 \frac{F_m}{F_a} \quad (2.2)$$

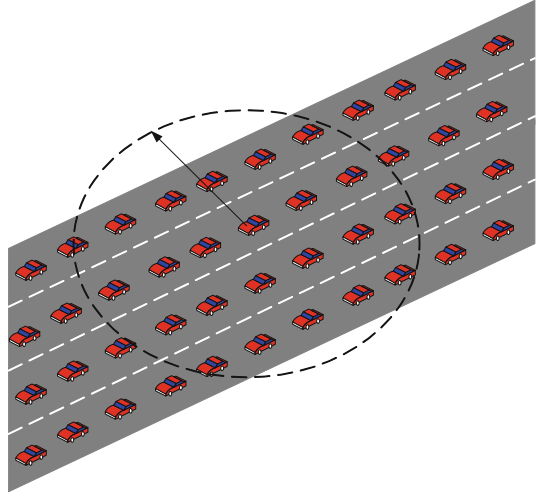
where F_m is the number missing data frames observed by a given vehicle and F_a is the total number of data frame that are expected to be received without any error.

For a given vehicle, optimal transmission range TR based on local vehicle density δ in (2.1) and the data collision rate P_c in (2.2) can be computed as [4]

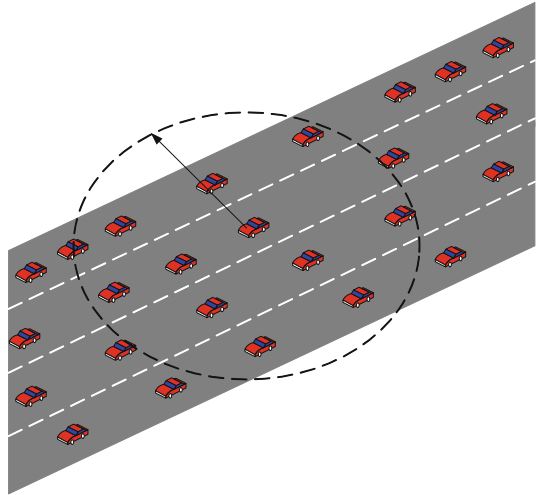
$$TR = \min \left\{ L, \min \left\{ L \frac{(1 - \delta)}{P_c}, \sqrt{\frac{L \log(L)}{\delta P_c}} + \alpha L \right\} \right\} \quad (2.3)$$

where L is the road segment and its maximum value in DSRC-enabled IEEE 802.11p based VANET is $L = 1000$ m, and α is a traffic flow constant [10]. Based on the transmission range calculated in (2.3), each vehicle can easily estimate its transmit power using wireless propagation models suitable for given environment (urban,

Fig. 2.1 Estimating local vehicle density $\delta = \frac{N_0}{N_p}$ on the road for a given vehicle for a given transmission range



(a) Number of ‘possible’ neighboring vehicles, N_p for a given transmission range.



(b) Actual number of ‘reachable’ neighboring vehicles, N_0 for a given transmission range.

city, rural, etc.). Note that GPS can easily suggest the location of the vehicle and then choose the suitable wireless propagation parameters such as path loss exponent for calculating transmission power. Mapping between transmission range and actual transmission power value can be done using look-up table as shown in Table 2.1 containing the transmit power values corresponding to different transmission ranges. Note that the look-up table approach is faster, since no computations are required to

Table 2.1 Look-up table for transmission power corresponding to a given transmission range

Transmission range (m)	Transmission power (dBm)
0–9	–20
10–49	–12
50–100	–5
100–125	–3
126–149	1
150–209	4
210–299	6
300–349	10
350–379	12
380–449	14
450–549	17
550–649	20
650–749	24
750–849	27
850–929	29
930–970	31
971–1000	32
> 1000	N/A in DSRC

convert transmit range to transmit power. Values in Table 2.1 were obtained by Monte Carlo simulations of wireless propagation models for different vehicular scenarios and a specific power value is assigned for a given transmission range interval to include urban, city, and rural environments [4].

2.3 Contention Window Adaptation

Along the line of IEEE 8-2.11e EDCA [11], messages in VANET can be grouped into four different priorities through message categories MC as shown in Table 2.2 with their minimum and maximum contention window sizes. Each message category generates a timer value from $[W_l, W_h]$ to get a transmission opportunity where W_l and W_h are, respectively, lower and upper bound of the contention window size.

The newly computed TR value (at $t + 1$) in (2.3) is compared against the previous TR value (at t) for a given vehicle to find whether transmission range increased or decreased to increase or decrease the contention windows. If $TR(t + 1)$ is greater than $TR(t)$, the traffic density around a given vehicle is decreased (since TR increased when vehicle density decreased) thus contention window can be decreased to increase the transmission opportunities. To adjust the maximum CW size W_h based on network

Table 2.2 Four message categories with CW size in VANET

Message Category (MC) in VANET	AIFS	W_l	W_h
MC_0 : Accident related messages	1	0	4
MC_1 : Warning messages	1	0	8
MC_2 : Periodic messages	2	4	16
MC_3 : All others data traffic	2	8	32

conditions, adaptation for CW for each message category m is carried out as

$$W_h^m = \begin{cases} \frac{W_h^m}{2}, & \text{if } TR(t+1) > TR(t) \text{ and } P_c^m < \bar{P}_c^m, \quad m = 0, 1, 2, 3. \\ 2W_h^m, & \text{if } TR(t+1) < TR(t) \text{ and } P_c^m > \bar{P}_c^m, \quad m = 0, 1, 2, 3. \\ W_h^m, & \text{otherwise, } m = 0, 1, 2, 3. \end{cases} \quad (2.4)$$

Note that the W_l is also decreased accordingly. Next the probability that the W_h window size is reduced by half can be expressed as

$$P_{\frac{W_h}{2}}^m = (1 - P_b^m)(1 - P_c^m)P_N^m \quad (2.5)$$

where P_b^m is the probability of the channel being busy and the probability P_N^m is given by

$$P_N^m = \left(1 - \frac{\lambda_m}{\mu_m}\right) \left(\frac{\lambda_m}{\mu_m}\right)^{N-1} \quad (2.6)$$

here λ_m is packet arrival rate and μ_m is the service rate for MC m .

2.3.1 Throughput and Delay Analysis

The network throughput θ_m for each message category m is analyzed with the changing W_c parameter. The probability of successful packet transmission P_s^m can be expressed as

$$P_s^m = P[T_s^m \leq t_t] \cdot P_{\frac{W_h}{2}}^m \quad (2.7)$$

where $P[T_s^m \leq t]$ is the probability that the data packet is transmitted within a given time (t_t depends on TR and the relative velocity v of the vehicles since $t = TR/v$ and $T_s^m = \frac{D}{R}$).

Then the normalized throughput for a given message category m in VANET can be expressed as

$$\theta_m = \frac{P_s^m \cdot T_s^m}{P_i^m \cdot T_i^m + P_s^m \cdot T_s^m + P_c^m \cdot T_c^m + P_{frz}^m \cdot T_{frz}^m} \quad (2.8)$$

where P_i^m is the probability of a channel being idle after a collision or after a successful transmission and T_i^m is the channel being idle. P_{frz} is the probability of counter being frozen for the time T_{frz}^m . Then the normalized average throughput per vehicle by considering all MCs in VANET is $\theta = \sum_{m=1}^4 \theta_m/4$.

Next, end-to-end delay Δ_m by a given vehicle for a particular message category can be calculated as

$$\Delta_m = (P_{\frac{W_h}{2}}^m)^{N-1} \cdot (N-1) \cdot [AIFS^m + T_{frz}^m + W_c^m + T_c^m]. \quad (2.9)$$

2.4 Performance Evaluation

This section presents performance evaluation results to corroborate the theoretical analysis by using numerical results obtained from simulations. In the simulation setup, vehicles are assumed to be equipped with computing and communication devices for vehicular communication using IEEE 802.11p WAVE. Each vehicle maintains a safety distance to avoid collisions with other neighboring vehicles. Individual vehicles are assumed to be broadcasting their status (speed, location, direction, etc.) periodically (10 times every second in DSRC-enabled IEEE 802.11p). A 10 mile (16.69 m) urban map using microscopic traffic Intelligent Driver Model (IDM) [12] in ns-2 with an initial vehicle speed in the range of 11–31 m/s (25–70 miles/h) is considered. The traffic constant α is assumed to be $\alpha = 0.25$ as per traffic flow theory [10]. Each vehicle estimates local vehicle density δ regularly using (2.1) using periodic status information and estimates the data collision rate in the network.

In the first experiment, the variation of transmission range TR versus the local vehicle density δ for different data collision probabilities is plotted as shown in Fig. 2.2. From Fig. 2.2, it can be observed that when local vehicle density increases, transmission range decreases. Similarly, for a given local vehicle density value (say $\delta = 0.4$), the transmission range TR decreases when data collision rate increases and vice versa. When there is no data collision at all in the network, vehicles could maintain their transmission ranges to maximum allowed values in DSRC-enabled VANET (i.e., 1000 m) as shown in Fig. 2.2 regardless of the vehicle density. Using this adapted transmission range, each vehicle can use look-up table to set its transmission power.

Next, the variation of delay for all four message categories versus the probability of getting transmission opportunities for the messages is plotted as shown in Fig. 2.3. Note that the delay for each message category depends on the corresponding probability of back-off timer W_c reaching zero for a given vehicle (which depends on data collision and local vehicle density). Higher the transmission opportunities, the lower the delay for a given MC is observed as shown in Fig. 2.3. Furthermore, we observed that the delay for highest priority (lowest MC) messages is lowest among all and highest for the lowest priority messages as shown in Fig. 2.3.

Then, the variation of delays for all message categories using adaptive approach and static approach against the probability of reducing the contention window size is

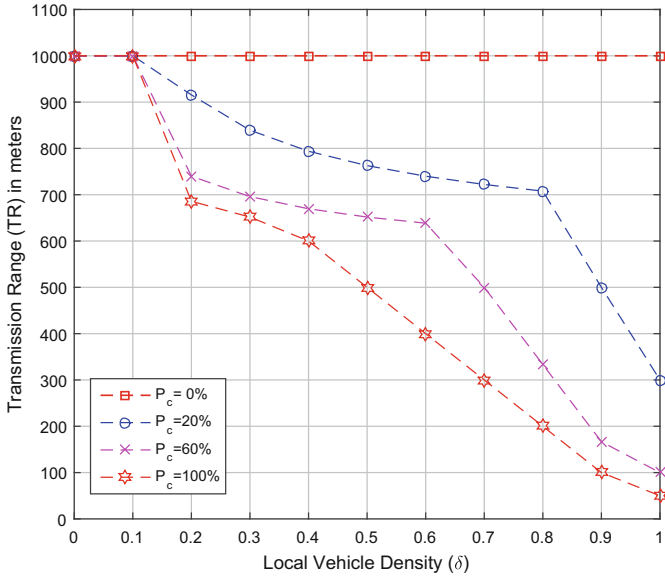


Fig. 2.2 Transmission range versus local vehicle density δ for different P_c values

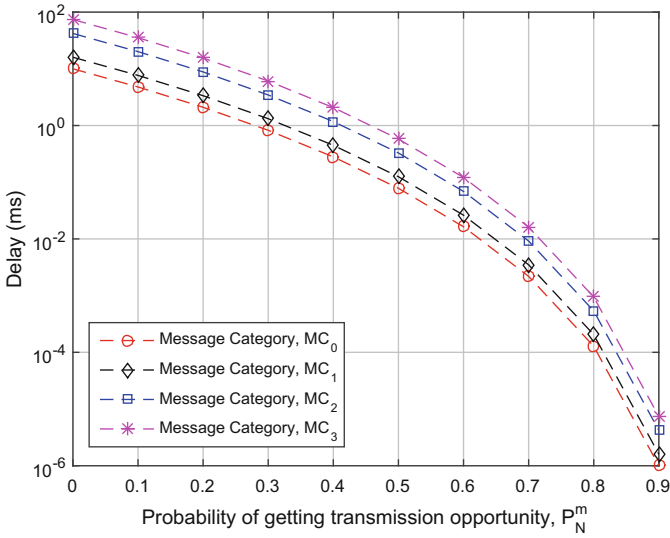


Fig. 2.3 Delay for each message category MC versus the probability of getting transmission opportunity

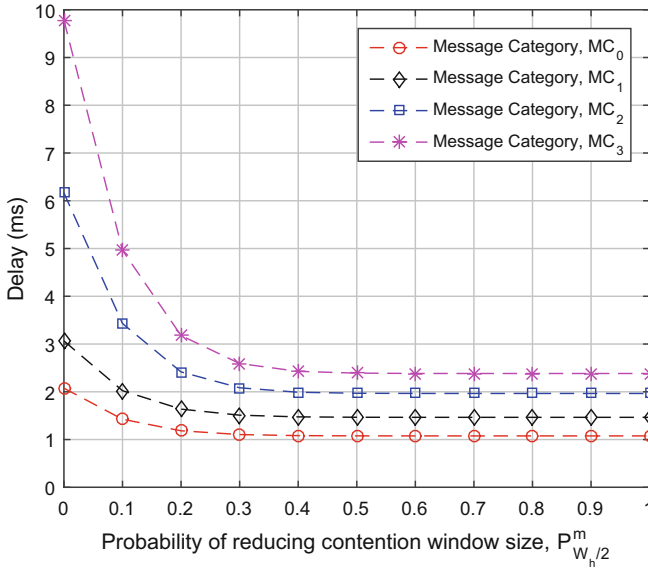


Fig. 2.4 Delay Δ_m for each MC versus probability of reducing the contention window size

plotted in Fig. 2.4. When the probability of reducing contention window increases, the delay decreases for each MC as shown in Fig. 2.4. Furthermore, for higher probability value than 0.4, the delay remains the same since there is no room to reduce the contention window size further.

Next, the variation of average of end-to-end delay for the adaptive approach and static approach versus simulation time is plotted as shown in Fig. 2.5. It can be observed that the adaptive approach gives lower delay than the static approach (where all parameters are fixed) and an approach presented in [4] as shown in Fig. 2.5. The adaptive approach gives better results, because it considers local vehicle density and data collision rate in the vehicular network, and adapts the transmission range and CW values on the fly. Note that in the beginning delay value is same for all approaches in Fig. 2.5, since adaptive approach takes some time to estimate and adapt parameters accordingly. After certain time, delay for adaptive approach is much lower than the other approaches as shown in Fig. 2.5.

Next, the variation of average of normalized overall throughput versus simulation time is plotted as shown in Fig. 2.6. It can be seen that the normalized throughput increases with simulation time and is higher for the adaptive approach than that of static approach and an approach presented in [4] as shown in Fig. 2.6. In the beginning throughput value is same for all approaches (as in Fig. 2.6), since adaptive approach takes some time to estimate to adapt parameters. However, after certain time, adaptive approach gives higher overall throughput than other approach as shown in Fig. 2.6.

In summary, it is observed that the adaptive approach gives higher throughput with lower end-to-end delay in vehicular communications.

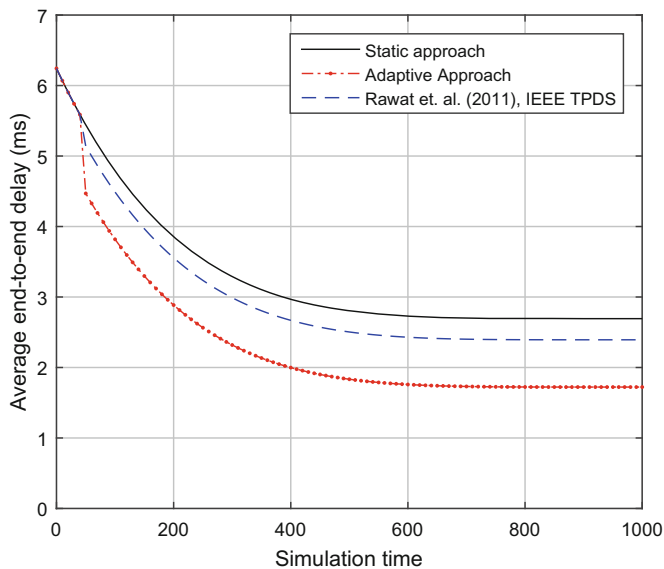


Fig. 2.5 Variation of average of overall end-to-end delay for adaptive approach and static approach versus simulation time

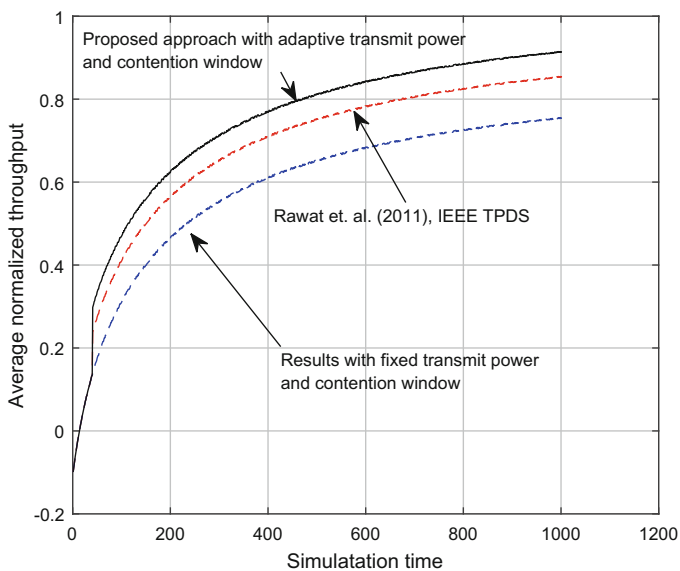


Fig. 2.6 Comparison of average of normalized throughput for approach with the static approach against simulation time

2.5 Summary

This chapter has evaluated the performance of dynamic adaptation of transmit power and contention window based on local traffic density and data collision rate in IEEE 802.11p enabled vehicular networks. Mathematical analysis is presented to study the impact of local vehicle density and data collision rate in the network. Specifically, the adaptive approach has incorporated adaptation of transmission range for each vehicle based on both local vehicle density and data collision rate in vehicular CPS, and adaptation of contention window for each message category based on the data collision rate. Performance is evaluated using numerical results obtained from simulations where the adaptive approach results in higher throughput with lower delay for all messages.

References

1. C. D. Wang and J. P. Thompson, "Apparatus and method for motion detection and tracking of objects in a region for collision avoidance utilizing a real-time adaptive probabilistic neural network," Mar. 18 1997, uS Patent 5,613,039.
2. D. S. Breed, W. E. Duvall, and W. C. Johnson, "Accident avoidance system," Apr. 9 2002, uS Patent 6,370,475.
3. D. B. Rawat, J. J. Rodrigues, and I. Stojmenovic, *Cyber-Physical Systems: From Theory to Practice*. CRC Press, 2015.
4. D. Rawat, D. Popescu, G. Yan, and S. Olariu, "Enhancing VANET Performance by Joint Adaptation of Transmission Power and Contention Window Size," *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, no. 9, pp. 1528–1535, Sept 2011.
5. D. B. Rawat, G. Yan, D. C. Popescu, M. C. Weigle, and S. Olariu, "Dynamic adaptation of joint transmission power and contention window in VANET," in *2009 IEEE 70th Vehicular Technology Conference Fall (VTC 2009-Fall)*, 2009, pp. 1–5.
6. H. Hartenstein and K. Laberteaux, *VANET: vehicular applications and inter-networking technologies*. Wiley Online Library, 2010, vol. 1.
7. S. Olariu and M. C. Weigle, *Vehicular Networks: From Theory to Practice*. CRC Press, 2009.
8. D. B. Rawat and S. Shetty, "Enhancing connectivity for spectrum-agile vehicular ad hoc networks in fading channels," in *2014 IEEE Intelligent Vehicles Symposium Proceedings*, 2014, pp. 957–962.
9. D. B. Rawat, B. B. Bista, G. Yan, and S. Olariu, "Vehicle-to-Vehicle Connectivity and Communication Framework for Vehicular Ad-Hoc Networks," in *2014 Eighth International Conference on Complex, Intelligent and Software Intensive Systems (CISIS)*, 2014, pp. 44–49.
10. W. R. McShane and R. P. Roess, *Traffic Engineering*, 1990.
11. D. B. Rawat, D. C. Popescu, and M. Song, "Performance enhancement of EDCA access mechanism of IEEE 802.11 e wireless LAN," in *2008 IEEE Radio and Wireless Symposium*, 2008, pp. 507–510.
12. M. Treiber, A. Hennecke, and D. Helbing, "Congested traffic states in empirical observations and microscopic simulations," *Physical Review E*, vol. 62, no. 2, p. 1805, 2000.



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