Chapter 8

Performance Analysis of the DSRC/IEEE 802.11p for VANETs Safety Applications

In this chapter, an logical model for the reliability of the Dedicated Short Range Communication (DSRC)/IEEE 802.11p, control channel to handle safety applications in vehicular ad-hoc networks is proposed. Specifically, the model enables the determination of the probability of receiving safety messages from all vehicles within the transmitters range, and validates this model by simulation. The proposed model is built, based on the new mobility model proposed in Chapter 5 that takes into account the vehicle’s follow-on safety rule, to accurately derive the relationship between the vehicle’s speed and network density. Moreover, the model takes into consideration:

a. Effect of mobility on vehicle’s density around the transmitter.

b. Effect of the transmitters and receiver’s speeds on the systems reliability.

c. Effect of channel fading since the communication range is modeled as random variable.

d. The hidden terminal problem and transmission collisions from neighboring vehicles.

It is shown, that the current specifications of the DSRC/IEEE 802.11p may lead to severe performance degradation in dense and high mobility conditions. Therefore,
an adaptive algorithm is introduced, to increase the system’s reliability, in terms of the probability of packets successful reception and time delay of emergency messages, in a harsh vehicular environment.

8.1 Overview

The research and application development in vehicular ad-hoc networks have been driven by the DSRC technology or IEEE 802.11p designed to help drivers to travel safely and to reduce the number of fatalities, due to road accidents. The IEEE 802.11p MAC uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and some concepts from the Enhanced Distributed Channel Access (EDCA) for Information technology. In this technology, there are four access classes (ACs) with different Arbitration Inter Frame Space Numbers (AIFSN) to insure less waiting time, for high priority packets, as listed in Table 4.3.

The DSRC/IEEE 802.11p is licensed at 5.9GHz with 75 MHz spectrum, which is divided into seven 10 MHz channels and 5 MHz guard band. The control channel (CCH) will be used for safety applications, while the other six channels, called service channels, will be used for infotainment or commercial applications, to make this technology more cost effective. Vehicles will synchronize the switching between the CCH and one or more of the service channels (SCH), hence, safety related messages will not be missed or lost. The synchronization interval (SI) contains a control channel interval (CCI) followed by a service channel interval (SCI) separated by a guard interval (GI) as shown in Figure 8.1. Increasing the CCI interval will enhance the reliability of safety applications and challenge the coexistence of both safety and non-safety applications, on the DSRC/IEEE 802.11p.

Vehicular ad-hoc network is a self-organizing network that works on both Vehicle-to-Vehicle Communication and Vehicle to infrastructure communication. In this analysis, Vehicle-to-Vehicle Communication is taken into consideration, where vehicles will be equipped with sensors and GPS systems to collect information about their position, speed, acceleration and direction, to be broad-casted to all vehicles within their range. In IEEE 802.11p, vehicles will not send any acknowledgement for the broad-casted packets. Therefore, the transmitter will not detect the failure of the message reception and hence will not retransmit it. This is a serious problem in collision warn-
ing applications, where all vehicles behind the accident have to receive the warning message successfully in a short time to avoid chain collisions. This problem motivates us, to propose an analytical model, for assessing the DSRC/IEEE 802.11p reliability and time delay, taking into account the Vehicular Ad-hoc Networks multi-path fading channel, vehicles high mobility, hidden terminal problem and transmission collisions.

8.2 Related Work

In the literature, there are many studies on the performance of DSRC/IEEE 802.11p [International] which are categorized into three different groups.

The first group is based on simulations and targeted only one parameter of the DSRC/IEEE 802.11p. The authors in (Hafeez et al., “The optimal radio propagation model in VANET”) and (Torrent-Moreno, Jiang, and Hartenstein) study the effects of radio propagation models in vehicular ad-hoc networks, based on the probability of successful reception rate. While (Torrent-Moreno et al., “Vehicle-to-vehicle communication: Fair transmit power control for safety-critical information”) focuses on how to control the load of periodic messages, to ensure the successful reception of warning messages. The authors in (Jiang, Chen, and Delgrossi) introduce a new method, for selecting the data rate in vehicular ad-hoc networks based on a simulation setup. They compare the performance of different broadcast transmissions using different data rates, while adjusting the power used in each scenario to maintain a comparable level of channel interference. In (Bilstrup et al.), the authors analyze the DSRC/IEEE 802.11p by simulations in terms of the channel access time delay. They show that using 802.11p MAC will result in an unbounded delay and compare it with a self-organizing time division multiple access (STDMA) scheme, which they prove is more suitable for vehicular ad-hoc networks real time safety applications.
In (Wang and Hassan), the authors propose, a framework for sharing the DSRC/IEEE 802.11p between vehicular safety and non-safety applications. By assuming uniform distribution of vehicles on the road, their simulations show that non-safety applications may have to be severely restricted, such that safety applications are not compromised, especially in high density networks.

In the second group, analytical models have been proposed, to study the DSRC/IEEE 802.11p MAC protocol. While (Xu, Sakurai, and Vu) and (Lee and Lee) analyze the EDCA (Bianchi), analyzes the IEEE 802.11 for uni-cast communication. Although DSRC is based on IEEE 802.11 and EDCA, their analytical models for performance evaluation of uni-cast communications, cannot be used for broadcast communication mode in IEEE 802.11p because no ACK is communicated. Therefore, the transmitter will not detect a collision from a successful transmission. The authors in (Ma and Chen, “Delay and Broadcast Reception Rates of Highway Safety Applications in Vehicular ad-hoc Networks”), introduce a one dimensional Markov chain, to calculate the delay and reception rate in vehicular ad-hoc networks but have not included the time delay in each stage due to busy channel. While in (Eichler), the authors analyze the system using, only the average delay for each access class and have not taken into account the back-off delay.

In (Ma and Chen, “Performance analysis of IEEE 802.11 broadcast scheme in ad hoc wireless LANs”) and (Ma, Zhang, and Wu), the authors, study the saturation performance of the broadcast scheme in vehicular ad-hoc networks, taking into account the back-off counter consecutive freeze situation. They assume saturation conditions, stationary distribution without considering the impact of vehicles mobility on the system performance. In (Fracchia and Meo), an analytical model, for delivering safety messages within inter-vehicle communication (IVC) is derived. They assume a perfect channel access and have not accounted for the hidden terminal problem, collision probability and vehicle’s mobility. The authors in (Hassan, Vu, and Sakurai) study the performance of IEEE 802.11p based on time delay of status packets, by modeling each vehicle as an M/G/1 queue with an infinite buffer, without taking vehicles mobility into consideration.
In the last group, the authors study the connectivity in vehicular ad-hoc networks, for example (Khabazian and Ali) – (Desai and Manjunath), (Jin and Recker) and (Abuelela, Olariu, and Stojmenovic). Most of these studies are based on the assumption, that nodes have a uniform stationary distribution in the network, such as (Ghasemi and Nader-Esfahani) and (Desai and Manjunath). In (Jin and Recker), the authors present, an analytical model for multi-hop connectivity, assuming that vehicles positions are known by either simulation or observation. They assume, the propagation of information is instantaneous with respect to vehicles movement.

In (Khabazian and Ali), the authors derive a mobility model for vehicular ad-hoc networks, considering the arrival of vehicles to a service area as a Poisson distribution and did not include the follow-on safety rule. While in (Abuelela, Olariu, and Stojmenovic), the authors derive the probability of no end-to-end connectivity between clusters of vehicles distributed uniformly on the road. They introduce a new opportunistic message relaying protocol that switches between data mulling and local routing, with the help of vehicles in the other direction. In contrast to our mobility model introduced in Chapter 5, all of these models, do not consider how the speed of transmitters and receivers affects the connectivity probability and the message reception rates.

In this chapter, an logical model, for the analysis of new broadcast services in the DSRC/IEEE 802.11p protocol, considering the high mobility of vehicles on highway roads, the hidden terminal problem, collision probability and non-saturation conditions are resolved. The new analysis is based on the mobility model derived in Chapter 5 which takes into consideration of the vehicle’s follow on safety rules and regulation as per Indian scenario which will accurately derive the relationship between the vehicles density and their speed on highway. The new mobility model considers, how the speed of transmitters and receivers affect the connectivity probability and the message reception rates. The message reception rate is derived, considering the distance between the transmitter and receivers, speeds and direction. The proposed model uses a Markov chain approach, which includes the probability of a carrier sense busy channel in each state, to derive the probability of transmitting status and warning messages and their time delay. Based on the logical and NS2 simulation results, an new adaptive and mobility algorithm, is introduced to enhance vehicular ad-hoc
networks performance.

8.3 System Model and Performance Metrics

In vehicular ad-hoc networks safety applications, vehicles broadcast different types of messages:

- Warning message.
- Emergency message.
- Local message.
- Status message.

While warning messages usually contain safety related messages, status messages are sent periodically to all vehicles, within their range and contain vehicles state information such as speed, acceleration, direction and position. Therefore, emergency messages will use $AC_3$ since it has the highest priority as listed in Table 4.3 while status message will use $AC_1$.

In the model, vehicles generate their status messages at a rate of $\lambda_s$ (Hafeez et al., “The optimal radio propagation model in VANET”), indicating that the length of the synchronization interval is $SI = \frac{1}{\lambda_s}$. Assume that all packets, have the same length $L$ bits and the whole SI interval is dedicated to safety applications, that is $CCI = SI$. Each vehicle will randomly choose a slot within the $SI$ interval to transmit its status message. Emergency messages are sent only during emergency situations such as an accident or a warning from hazards or a jam on the road ahead. Based on these assumptions, DSRC protocol is analyzed to find the smallest channel interval that maximizes the reliability of safety applications. Thus achieve high probability of receiving a status message from each vehicle node within this interval successfully.

It is assumed, that all vehicles have the same transmitting power ($P_t$) and each vehicle receives the signal successfully if the received power is higher than a certain threshold $P_{th}$. Since fading is a major characteristic of vehicular ad-hoc networks channel, the received signal power is random and therefore, the communication range is also a random variable.
8.4 Link Availability Probability

Two vehicles can communicate only if they are within the communication range of each other. Therefore, the probability of successfully receiving a message depends on the relative speed between the sender and the receiver, the message transmission time and the transmitter’s range $R$. Assume initially that the receiver is at an arbitrary distance from the transmitter but within the communication range, at the beginning of the message transmission. Let $d_1$ be the distance of the receiver from the sender, that is moving in the same direction as the sender as shown in Figure 8.2. Then the probability density function, of this distance is $f_{d_1}(x) = \frac{1}{2R}$. Since the status message transmission time $T_t$ is very short, assume that the vehicles speed will not change during this time period. If the receiver is at distance $d_1$ from the sender, then its new location from the sender at the end of the message transmission is $d_n = d_1 + (v_x - v_t)T_t$, where $v_t$ and $v_x$ are the transmitter’s and receiver’s speeds respectively. Therefore, the probability $P_l$ that a vehicle, which is traveling in the same direction, will receive
the message, successfully, is when its $d_n$ is still within the transmitter’s range as

$$P_l = P(-R < d_1 + (v_x - v_t)T_t < R). \quad (8.1)$$

From (8.1), if the receivers speed $v_x \geq v_t$, then vehicles located at distances less than $-R$ at the time of transmission are not considered. Therefore, the probability $P_{l_1}$ that a vehicle traveling at a higher speed than the transmitter will receive the message successfully is given by

$$P_{l_1}(v_t) = \int_{v_t}^{v_{\text{max}}} \int_{-R}^{-R-(v_x-v_t)T_t} \frac{1}{2R v_{\text{max}} - v_t} dx dv_x$$

$$P_{l_1} = 1 - \frac{v_{\text{max}} - v_t}{4R} T_t \quad (8.2)$$

On the other hand, if the receiver speed $v_x < v_t$, then vehicles node located at distances greater than $R$ at the time of transmission is not considered. Therefore, the probability $P_{l_2}$ that a vehicle traveling with a speed lower than the transmitter will receive the message successfully, is given by

$$P_{l_2} = \int_{v_{\text{min}}}^{v_t} \int_{-R+(v_x-v_t)T_t}^{R} \frac{1}{2R (v_t - v_{\text{min}})} dx dv_x$$

$$P_{l_2} = 1 - \frac{v_t - v_{\text{min}}}{4R} T_t \quad (8.3)$$

Since a vehicle node traveling at a speed lower than the transmitting vehicles node speed with probability $\omega = \frac{v_t - v_{\text{min}}}{v_{\text{max}} - v_{\text{min}}}$, the probability $P_l(v_t)$ that a vehicle node traveling in the same direction as the transmitting vehicle node will receive the message successfully is given by

$$P_l(v_t) = P_{l_1}(v_t)(1 - \omega) + P_{l_2}(v_t)\omega \quad (8.4)$$

Integrating (8.4) over the range $v_t \in [v_{\text{min}}, v_{\text{max}}]$ yields the probability of receiving a message successfully due to mobility $P_l$ as

$$P_l = 1 - \frac{v_{\text{max}} - v_{\text{min}}}{8R} T_t. \quad (8.5)$$
8.5 Waiting Time and Contention Window Process

A model for the waiting time counter process of the IEEE 802.11p, for single access class is constructed as shown in Figure 8.3. If a vehicle has a status message, it will wait initially for a period of $AIFS = SIFS + AIFSN \times \phi$ before it can broadcast the message, where $AIFS$ is the Arbitration Inter Frame Space for status message access class, $AIFSN$ is the Arbitration Inter Frame Space number associated with this class as listed in Table 2.3 and $\phi = 13\mu s$ is the length of the time slot. If the channel is sensed busy (with probability $p$) during the $AIFS$ time. The access class (AC) will choose a contention window ($W_o$) uniformly and randomly from $[0, ..., W_s - 1]$ as a waiting time counter, where $W_s$ is the minimum contention window associated with this class. At any time slot, during the waiting time process with probability $(1-p)$, the AC decrements its waiting time counter if it senses an idle channel. Otherwise it freezes the counter and waits for the whole period of the ongoing transmission ($T_t = \frac{L}{r_d} + AIFS + \delta$), until the channel is idle again before decrementing its counter, where $p$ is the conditional busy channel, probability seen by a message about to be transmitted and independent from any other vehicle, $\delta$ is the propagation delay and $r_d$ is the data rate. Once the waiting time counter reaches the zero state, the AC broadcasts the message. There will be no subsequent retransmissions, if the message is collided and hence the message is lost (Sjoberg) (Hafeez).
To find the probability \( \tau_s \) that a vehicle node transmits a status message in a randomly selected slot, to solve the Markov chain in Figure 8.3. First define \( b(t) \in [0, ..., W_s - 1] \) as the random process for the status message queue in each vehicle, where \( t \) is a discrete and integer time that decrements at the beginning of each time slot. Second, define \( k \in [0, ..., W_s - 1] \) as the waiting time counter value and \( b_k = \lim_{t \to \infty} P\{b(t) = k\} \) as the stationary distribution of the Markov chain. Therefore, solve the discrete Markov chain as

\[
 b_k = \frac{W_s - k}{W_s} \frac{p}{1 - p} b_0, 1 < k < (W_S - 1) \tag{8.6}
\]

By using (8.6) and the normalized condition \( 1 = \sum_{k=0}^{W_s-1} b_k \), can solve for \( b_0 \) as follows

\[
 b_0 = \frac{2(1 - p)}{2 - 3p + pW_s} \tag{8.7}
\]

To derive the probability \( \tau_s \) that a vehicle node transmits an emergency message in a randomly selected slot: First, the vehicle node has to have a status message, ready to transmit with probability \( (\varrho \lambda_s) \). Second, it will transmit this message, with probability of \( (1 - p) \), only when the waiting time counter reaches zero state. Therefore, the probability \( \tau_s \) can be derived as

\[
 \tau_s = \frac{2(1 - p)^2}{2 + pW_s - 3p} (\varrho \lambda_s) \tag{8.8}
\]

If at least one vehicle node within the carrier sense range, is transmitting a message in the same time slot when the channel is sensed busy, \( p \) can be expressed as

\[
 p = 1 - \sum_{k=0}^{\infty} (1 - \tau_s)^k P_{2LCS}(k)
\]

\[
 p = 1 - \sum_{k=0}^{\infty} (1 - \tau_s)^k \left( \frac{2\beta_i R}{\mu \sqrt{\rho}} \right) e^{\frac{-2\beta_i R}{\mu \sqrt{\rho}}}
\]

\[
 p = 1 - e^{\frac{-2\beta_i R}{\mu \sqrt{\rho}} \tau_s}, \tag{8.9}
\]

where \( P_{2LCS} (k) \) is Equation (5.26) which is the probability of having \( k \) vehicles within the carrier sense range. The Newton-Raphson method is used to solve (8.8) and (8.9) since the system has a unique solution in the range of \( p \in [0, 1] \) as shown in the simulation section.
The average time delay $E[T_{ss}]$ for a status message to be transmitted from the time it was ready at the MAC layer can be derived from the Markov chain in Figure 8.3 as

$$E[T_{ss}] = T_{sq} + E[T_{sf}] + T_t,$$  \hspace{1cm} (8.10)

where $T_{sf}$ is the time delay due to waiting time process, $T_t = \frac{L_r}{r_0} + AIFS_{[AC1]} + \delta$ is the message transmission time, and $T_{sq}$ is the queuing delay, which is negligible in this case, since a vehicle will produce one status message in every $SI$ interval and if a new message is generated it will replace the old one. Therefore,

$$E[T_{ss}] = \sum_{i=0}^{W_s-1} \frac{p}{W_s} \sum_{k=0}^{i-1} (pT_t) + T_t$$

$$E[T_{ss}] = \frac{p^2T_t(W_s - 1)}{2} + T_t$$  \hspace{1cm} (8.11)

### 8.6 Probability of Successful Reception

For successful reception by another vehicle node located within the tagged vehicles node range $R$. It is imperative that no vehicle node within its carrier sense range $(2E[L_{CS}])$ (or within the maximum $4R$ if $E[L_{CS}] > 2R$) will transmit in the same time slot in which the tagged vehicle node is transmitting. At the same time, vehicle nodes within the interfering areas, which is at maximum, equal to $2(2RE[L_{CS}])$ if $E[L_{CS}] < 2R$. They should not transmit during the vulnerable interval of un-slotted CSMA/CA. It equals two transmission periods weighted by the time slot $T_v = \frac{2T_t}{R_s}$. The transmitted message has also to be error free and the received signal strength has to be higher than the threshold $P_{th}$ which have been accounted for in the derivation of the average communication and carrier sense ranges in (5.5) and (5.7), respectively. Moreover the vehicle node has to stay within the range of the transmitting vehicle node, for the whole communication period. Putting all these conditions together, the probability of successful reception $P_s$ that a vehicle node within the communication range of the tagged vehicle node receive the status message successfully can be written as

$$P_s = P_l \cdot \left( \sum_{k=0}^{\infty} (1 - \tau_s)^k P_{dc}(k) \right) \left( \sum_{k=0}^{\infty} (1 - \tau_s)^k P_{dh}(k) \right)^T, \hspace{1cm} (8.12)$$

where $d_c = 2\min(E[L_{CS}], 2R)$ is the contention area and $d_h = 2\max(2R - E[L_{CS}], 0)$ is the hidden terminal area and can be calculated from (5.24). Therefore, $P_s$ can be
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simplified as

\[ P_s = \begin{cases} 
  P_l \cdot e^{-(1+T_c(2V_0^p-1)) \frac{2\alpha \rho}{\rho p} \tau_s}, & \rho > 0.5^a \\
  P_l \cdot e^{-2 \frac{2\alpha \rho}{\rho} \tau_s}, & \rho < 0.5^a
\end{cases} \tag{8.13} \]

This probability expresses the reliability of the designed system on Mumbai-Pune Express Highway, India. The higher the success rate, the more vehicle nodes will receive the emergency and status messages successfully, which will increase the drivers awareness of potential dangers on the road ahead.

8.7 Emergency Time delay

When a vehicle node encounters an emergency situation such as an accident, lane change or slowing down below a certain threshold speed is analyzed. The vehicle node that is involved in an emergency situation will send an emergency message to all vehicle nodes behind it. These will select another vehicle nodes as a relay node to rebroadcast the message to their neighbors. The emergency message continues to propagate until it reaches a certain distance \( D \) defined within the message itself.

The vehicle node uses the high priority access class \((AC_3)\) to send the emergency message after sensing an idle channel for an \( AIFSN \times \rho \) seconds, where \( AIFSN = 2 \) for this class as listed in Table 2.3. If the channel is sensed busy, the access class selects a contention window from the range \([0,W_e]\), where \( W_e = 3 \) in this case, and starts decrementing this counter as in the Markov chain in Figure 8.3. Therefore, the probability \( \tau_e \) that the emergency message will be sent, can be derived by analyzing the Markov chain as in (8.8) except changing \( W_s \) by \( W_e \) as

\[ \tau_e = \frac{2(1-p)^2}{2 + pW_e - 3p} \tag{8.14} \]

The average time delay \( E[T_{se}] \) for the emergency message to be transmitted from the time it was ready at the MAC layer can also be derived as in (8.11) as

\[
E[T_{se}] = \sum_{i=0}^{W_e-1} \frac{p}{W_e} \sum_{k=0}^{i-1} (pT_l) + T_l \\
E[T_{se}] = p^2 T_l (W_e - 1) + T_l \tag{8.15}
\]

Once the vehicle nodes are located within the communication range, receive the emergency message, they have to rebroadcast the message to the next hop. Vehicle
nodes calculate their probability of retransmitting the message and their waiting time based on their distance from the transmitter and the vehicle nodes density. The farthest vehicle from the transmitter will have higher retransmitting probability \( P_{tr} \) and less waiting time \( T_w \) as

\[
P_{tr}(d) = \frac{1}{2} \left[ \left( \frac{d}{R} \right) + \left( 1 - \frac{\beta \mu}{N_l} \right) \right]
\]

\[
T_w(d) = \left( 1 - \frac{d}{R} \right) \left( \frac{\beta \mu}{N_l} \right) (2T_t + \delta)
\]

where \( d \) is the inter distance between the transmitter and the potential relay vehicle node, (based on the received signal strength), \( N_l \) is the number of lanes on the Mumbai-Pune Express Highway Road, \( \beta \mu \) is the current vehicle density and \( \frac{N_l}{10} \) is the maximum vehicle node density, that is, jam scenario.

To derive the total travel time, for the emergency message to reach the distance \( D \), it is required to find the location of the farthest relay vehicle node to the transmitter, that received the message successfully and the time it waits, before it retransmits the message to the next hop. Assuming that the relay vehicle node is located at distance \( d \) from the transmitter as in Figure 8.4, then the probability \( P_{rec} \) that this relay vehicle node will receive the message successfully (assuming that the message is transmitted with probability \( \tau_e \)), can be derived in two cases:

- First when \( 0 < d < L_{cs} - R \), in this case the relay vehicle would receive the message successfully, when all vehicle nodes within the range \([d - L_{cs}, d + R] \) do not use the channel in the same time slot as the transmitter.
• Second case is when \( L_{cs} - R < d < R \), in this case, vehicle nodes within the range of \([d - L_{cs}, L_{cs}]\) should not use the channel in the same time slot as the transmitter and the vehicle nodes within the range \([L_{cs}, d + R]\) should not use the channel for the vulnerable period \( T_v \).

Therefore, \( P_{rec} \) can be derived in the same way as in (8.13) as

\[
P_{rec}(d) = \begin{cases} 
  P_t \cdot \tau_e \cdot e^{-\frac{\beta}{\nu + \psi \tau_s}}, & 0 < d < L_{CS} - R \\
  P_t \cdot \tau_e \cdot e^{\frac{\beta}{\nu + \psi}(2 - d + d + R - \frac{\beta}{\nu + \psi})}, & L_{CS} - R < d < R 
\end{cases}
\] (8.18)

It is obvious that farther the relay vehicle node is, the less number of hops the emergency message will travel and has less travel time delay. But as \( d \) increases, the relay vehicle is more vulnerable to the hidden terminal problem especially in high density Mumbai-Pune Highway scenario. Therefore, a condition of receiving the emergency message with probability \( P_{rec}(d) \geq 90\% \) is applied to find the average, inter distance \( d \) of the relay vehicle node from the transmitter. Since this relay vehicle node has a retransmission probability of \( P_{tr}(d) \), its average waiting time, till it transmits the emergency message is \( T_{w}(d)P_{tr}(d) \). The average number of hops, the emergency message will travel to reach its intended distance \( D \) is \( \lfloor \frac{D}{d} \rfloor \). Therefore, the average emergency message travel time to reach a distance \( D \) is

\[
T_{travel} = \left( \frac{D}{d} \right)(E[T_{se}] + \frac{T_{w}(d)}{P_{tr}(d)})
\] (8.19)

8.8 Adaptive and Mobility Algorithm for VANET

As per above the analysis, it can be seen that there are many conflicting parameters that affect the systems reliability and its success rate. Keeping these parameters with fixed values, as specified in the standard (International), will result in undesired performance, especially in a harsh vehicular environment where vehicles are moving at very high speed and their density on the road is changing very frequently. That is, in a matter of seconds, the vehicle density could change from light density to a jam scenario. Therefore, vehicles have to change their sending rate (\( \lambda_s \)), communication range (\( R \)) or (transmission power), carrier sense range (\( L_{CS} \)) and/or their minimum contention window size (\( W_s \)) based on situation on the road in order to increase the success rate and VANETs reliability.
Therefore, a new Adaptive and Mobility Algorithm (AMA) in which vehicle nodes change their parameters according to their density and speed on Mumbai-Pune Express Highway road, pertaining to the following assumptions, is proposed:

a. The vehicle nodes know their current average speed \( V_c \) and their maximum allowed speed \( V_{\text{max}} \) on Mumbai-Pune Express Highway road.

b. The maximum communication range (or the maximum transmission power) is set to \( R_{\text{max}} \) and the minimum communication range is set to \( R_{\text{min}} \) which is used in the jam scenario.

c. The carrier sense parameter (\( \rho \)), in Equation (5.6), can take three values \( \rho \in [1, 0.75, 0.5, 0.25] \).

d. The vehicle’s status message sending rate can take the values in the range of \([1 − 20]\).

e. The minimum contention window size \( W_{\text{sc}} \) can take on values in the range \([3 − 1023]\) with a step size of 16.

f. The current used vehicles average speed, range, carrier sense parameter, message sending rate and the minimum contention window are denoted as \( V_c, R_c, \rho_c, \lambda_{\text{sc}}, W_{\text{sc}} \), respectively.

Vehicle nodes will execute the AMA algorithm every \( T_{\text{alg}} \) seconds, where they sense the vehicle nodes density from their current average speed and compare it with the maximum speed \( V_{\text{max}} \). The pseudo-code of the AMA algorithm is shown as Algorithm 2. The smaller the current vehicles average speed within the previous time period \( T_{\text{alg}} \), the higher the vehicle node density will be around that vehicle node, based on the proposed mobility model in Chapter 5. The algorithm divides the range \( (R_{\text{max}} − R_{\text{min}}) \) into ten steps. Each time, the vehicle node speed is dropped by a tenth of its maximum speed \( V_{\text{max}} \), it will reduce its range and set the other parameters accordingly. The vehicle will calculate its delay \( (T_b) \) from the time it was ready to transmit its status message, until the time the message is transmitted. If the new value of \( T_b \) is higher than the old one by \( \pi = 10\% \), the vehicle will increase its minimum contention window size \( W_{\text{sc}} \); otherwise it will decrease it or keep it the
The carrier sense range is also set according to the sensed density. When the vehicle’s density is high, the carrier sense range is decreased in order to decrease the waiting time for each vehicle to send its status message. Although decreasing the carrier sense range will increase the hidden terminal area, the algorithm deals with this problem by decreasing the communication range. Therefore, the AMA algorithm allows more vehicles to send their status messages within the synchronization interval with high successful reception rate.

Table 8.1: Value of parameters used in simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulation and Data rate</td>
<td>BPSK, 3 Mbps, 6 Mbps</td>
</tr>
<tr>
<td>Message and Header sizes</td>
<td>512, 250 Bytes, 64 Bytes</td>
</tr>
<tr>
<td>Status packets rate ( \lambda_s )</td>
<td>10 – 20 packets/s</td>
</tr>
<tr>
<td>vehicles speed</td>
<td>80 – 120 Km/h</td>
</tr>
<tr>
<td>vehicles arriving rate ( \beta )</td>
<td>1 vehicle/s</td>
</tr>
<tr>
<td>Exponent factor ( \alpha )</td>
<td>2.00, 4.00</td>
</tr>
<tr>
<td>Communication range ( R )</td>
<td>300 m, 600 m</td>
</tr>
<tr>
<td>Transmission power ( P_t (300 m) )</td>
<td>20 mW, 30 mW</td>
</tr>
<tr>
<td>Emergency Min. Contention Window ( W_e )</td>
<td>3, 15, 25</td>
</tr>
<tr>
<td>Status Min. Contention Window ( W_s )</td>
<td>15, 500, 1023</td>
</tr>
<tr>
<td>Received power threshold ( P_{th} )</td>
<td>3.162e – 13 W</td>
</tr>
<tr>
<td>Carrier sense power percentage ( \rho )</td>
<td>0.25, 0.5, 0.75, 1</td>
</tr>
<tr>
<td>Noise-floor</td>
<td>1.26e – 14 W</td>
</tr>
<tr>
<td>( T_{tx} &amp; T_{rx} ) antennas heights</td>
<td>1.5 m</td>
</tr>
</tbody>
</table>
8.9 Model Validation and Simulation

The DSRC performance will be analyzed based on the probability of successful reception derived in (8.13). All vehicles send their status messages except for one vehicle that sends an emergency message in which the time it takes to propagate to a certain distance 3000 meters is of interest. It is assumed that all vehicles are synchronized to the control channel interval all the time and the generation time of each status message is uniformly distributed over that interval.

To validate the model, NS-2.34 with realistic mobility models generated by MOVE (Karnadi, Mo, and Lan), which is built on top of the micro-traffic simulator SUMO (Krajzewicz et al.) that has the most realistic mobility traces for VANETs (Harri, Filali, and Bonnet). The simulation setup is a one directional highway segment of 4000 m length with 4 lanes. The vehicles’ speeds range from 80 – 120 km/h, which is typical for highways.

The Nakagami-m propagation model is used, which has two distance dependent parameters, the fading factor $m$ and the average power $\Omega$. The authors in (Torrent-Moreno et al., “IEEE 802.11-based one-hop broadcast communications: understand-
performed a maximum likelihood estimation of \( m \) and \( \Omega \) for vehicular highway scenario. They found that \( \Omega \) decreases as the distance to the receiver increases, as expected from the average power in the deterministic models, that is by \( d^{-2} \). On the other hand, fading parameter \( m = 3 \) is selected for short inter distance between the transmitter and the receiver \( (d < 50) \), since line of sight condition is expected, then decrease it to \( m = 1.5 \) for medium distances \( (50 < d < 100) \) and make it as Rayleigh distributed, i.e., \( m = 1 \) for longer distances. \( \Omega \) is set in each interval to be the average power calculated from a free space propagation model; hence receivers located within 100 \( m \) of the transmitter will receive the signal with Rician distribution, while others will have Rayleigh distribution. Since the receiver in NS2.34 will receive the signal, if its power is higher than the threshold \( P_{th} \), the transmitting power is set such that the receiving power at the communication range \( R \) is the threshold \( P_{th} \) as per (5.5), and the carrier sense range \( E[L_{CS}] \) is as in (5.7). Each simulation is performed for a period of 300 seconds of real time. Table 8.1 lists the simulation parameters used, unless a change is mentioned explicitly (Hafeez et al., "The optimal radio propagation model in VANET").

The following four metrics are defined to evaluate, the accuracy of the proposed model and reliability of the DSRC protocol in VANETs.

- First: the effective communication range, which is the range of most vehicles (96%) that are located around the transmitter, thus receive the transmitted message successfully and compare it with the communication range derived from (5.5).

- Second: The success rate, which is the number of vehicles that received the transmitted message successfully, divided by the total number of vehicles that are within the range of the transmitter and compare it with (8.13).

- Third: the average time delay, for a vehicle to send its status message and compare it with the time delay derived in (8.11).

- Fourth: the system reliability, which is the number of vehicles that managed to send their status message within the synchronization interval (SI) and received
8.9. MODEL VALIDATION AND SIMULATION

Figure 8.5: Effective communication range versus vehicle density when the success rate is set at 96% for different status message sending rates.

The results shown in Figure 8.5 - 8.8 are based on the vehicle density and average speed corresponding to the density extracted from Figure 5.4. Specifically, Figures. 8.5, 8.6, 8.7 and 8.8 show respectively the effective communication range, the success rate, status message delay and the reliability versus the vehicle density for different status packets generation rates. It is obvious that as the vehicle density increases, the effective range and success rate will decrease. At the same time the status message delay will increase resulting in decreasing the systems reliability, since the number of vehicles that have the chance to send their status messages will decrease. This means that not all vehicles, get the chance to access the channel and send their status packets. To improve the system reliability, the status message generation rate is reduced from 10 to 5 and then 2 packets/s. This improves the system reliability and success rate but it is still below the threshold of 95%, especially when the vehicle density is high. In order to meet this threshold for any vehicle density, vehicles have to reduce their communication range based on Figure 8.5.

Figures. 8.9, 8.10, 8.11 and 8.12 show respectively, the effective communication range, the success rate, status message delay and the reliability versus the vehicle
Figure 8.6: The successful rate versus vehicle density for different status message sending rates.

Figure 8.7: Status packets time delay versus vehicle density for different status message sending rates.
density for different carrier sense ranges. The carrier sense range is increased by decreasing the carrier sense power or the parameter $\rho$ in Equation 5.6. By decreasing $\rho$ from 1 to 0.25, the carrier sense range doubles that of the communication range. It is evident that increasing the carrier sense range will increase the contention region and decrease the hidden terminal region. Therefore, increasing the carrier sense range will increase the success rate and the system reliability, for fixed vehicle density as shown in Figures 8.10 and 8.12, respectively. As a consequence, the effective communication range will increase as shown in Figure 8.9. At the same time, vehicles will take longer to access the channel as shown in Figure 8.11 due to the increase in the number of vehicles contending for the channel. As a result, the number of vehicles that have chance to send their status messages will decrease and can be observed from the difference between Figs. 8.10 and 8.12.

To find the impact of the minimum contention window size ($W_s$) on VANETs, $W_s$ is increased from 15 to 1023. The success rate, status message delay and the reliability for different vehicle densities are plotted in Figures. 8.13, 8.14 and 8.15, respectively. It is shown that increasing the minimum contention window will decrease the probability of message collisions between vehicles, which is obvious from Figure 8.13, since the successful rate increases by the increase of $W_s$. It is also shown that
there is an optimal value of $W_s$ which gives the maximum success rate, since increasing it would not further result in much increase in the success rate. At the same time, the status message delay will increase dramatically by increasing $W_s$ especially when the vehicle density is high. This will result in decreasing the system reliability since not many vehicles might have the chance to send their status messages as shown in Figure 8.15.

To evaluate the effect of the AMA algorithm on VANET reliability, the main simulation parameters as in Table 8.1, are applied and let one vehicle send an emergency message which should propagate for a distance of $3 - 4$ $Km$ behind the transmitter. Figures. 8.16 and 8.17 show respectively the time delay until the emergency message reaches the intended distance and the percentage of vehicles that receive it successfully, with and without, using the AMA algorithm. It can be seen that the time needed for the emergency message, to reach the intended distance increases, as the vehicle density increases, due to the increase in channel contention and collisions. Adapting the AMA algorithm results in increasing the emergency time delay even more and this is because vehicles would decrease their communication range, as the vehicle density increases. It is also clear that the simulated time delay is close to the theoretical value derived from (8.19). On the other hand, adapting the new algorithm
Figure 8.10: The successful rate versus vehicle density for different carrier sense ranges.

Figure 8.11: Status packets time delay versus vehicle density for different carrier sense ranges.
8.9. MODEL VALIDATION AND SIMULATION

Figure 8.12: Systems reliability versus vehicle density for different carrier sense ranges.

Figure 8.13: The successful rate versus contention window size for different vehicle densities.
Figure 8.14: Status packets time delay versus contention window size for different vehicle densities.

Figure 8.15: Systems reliability versus contention window size for different vehicle densities.
increases the systems success rate dramatically especially in a high density scenario as shown in Figure 8.17. This means that more vehicles will be informed of the emergency situation on the road ahead, even though it arrives late but within tolerable delay as defined in (Mak, Laberteaux, and Sengupta).

8.10 Summary

An logical model is presented to analyze the reliability of the IEEE 802.11p in VANET safety and warning applications on Mumbai-Pune Express Highway, India scenario which consist of 2000 vehicles running on road. The analysis is based on a new mobility model in which the relationship between vehicles density, speed, direction and the follow-on distance rule is derived. In the analysis, several factors have been considered, such as the effect of mobility on the link availability between the transmitter and the receiver in same direction and different direction, the distribution of vehicles on the road and the average number of vehicles within the range of the transmitter. The proposed model is built on the fact that vehicles are broadcasting their status messages within the synchronization interval and model each vehicle as one-dimensional or two-dimensional Markov chain including, the channel busy in every state. It is shown analytically and by simulation that the effective maximum communication range is 1000 meter, that can be used in certain conditions to achieve certain

Figure 8.16: Emergency message travel time versus vehicles density.
Figure 8.17: Percentage of vehicles within the distance (3Km) that received the emergency message successfully.

It is shown from the analytical and simulation results that the current DSRC specifications may lead to undesirable performance under harsh vehicular environments. Therefore, a new Adaptive and Mobility Algorithm (AMA), is introduced to enhance VANET reliability. By using the AMA algorithm, vehicles are able to estimate the vehicle density and change their transmission parameters accordingly, based on their current average speed to enhance VANET performance. The simulation results, which coincide with the logical results, show that the proposed model is quite accurate to the simulation results in calculating the system reliability, scalability, efficiency which resolves the hidden terminal problem for Indian Mumbai-Pune Express Highway scenario.
Algorithm 2: Adaptive and Mobility Algorithm (AMA) to set VANETs parameters according to the vehicles density on the road.

1. Initial setup
2. \( R_{\text{max}} \leftarrow 1000; \)
3. \( R_c \leftarrow R_{\text{max}}; \)
4. \( P_c \leftarrow 0.25; \)
5. \( \lambda_{sc} \leftarrow 20; \)
6. \( W_{sc} \leftarrow 15; \)
7. \textbf{for Every} \( T_{\text{alg}} \) \textbf{seconds do}
8. \hspace{1em} \textbf{if} \( V_c < V_{\text{max}} \) \textbf{then}
9. \hspace{2em} \( i \leftarrow \left\lfloor \frac{V_c}{V_{\text{max}}} \cdot 10 \right\rfloor \) /* \( i \) represents a step from 1 to 10 in which the current speed falls in compared to the max. speed */
10. \hspace{2em} \( R_c \leftarrow R_{\text{min}} + i \cdot \frac{R_{\text{max}} - R_{\text{min}}}{10} \) /* use a new range based on the step \( i \) */
11. \hspace{2em} \( \lambda_{sc} \leftarrow \max(i, 1) \) /* use a new sending rate based on the step \( i \) */
12. \hspace{2em} \textbf{if} \( i \leq 3 \) \textbf{then}
13. \hspace{3em} \( \rho_c \leftarrow 1 \) /* in very high density, \( L_{CS} = R \) */
14. \hspace{2em} \textbf{else if} \( i \leq 5 \) \textbf{then}
15. \hspace{3em} \( \rho_c \leftarrow 0.75 \) /* in high density, \( R \leq L_{CS} = R \) */
16. \hspace{2em} \textbf{else if} \( i \leq 7 \) \textbf{then}
17. \hspace{3em} \( \rho_c \leftarrow 0.5 \) /* in medium density, \( R \leq L_{CS} \leq 2R \) */
18. \hspace{2em} \textbf{else}
19. \hspace{3em} \( \rho_c \leftarrow 0.25 \) /* in low density, \( L_{CS} \approx 2R \) */
20. \hspace{2em} \textbf{end if}
21. \hspace{2em} \textbf{end if}
22. \hspace{2em} \textbf{if} \( T_{\text{new}} \geq (1 + 3.16) \cdot T_{\text{bold}} \) \textbf{then}
23. \hspace{3em} \( W_{sc} \leftarrow \min(W_{sc} + 16130) \) /* if the time delay increases, i.e. more contention, increase \( W_s \) */
24. \hspace{2em} \textbf{else}
25. \hspace{3em} \( W_{sc} \leftarrow \max(W_{sc} - 1620) \) /* if the time delay decreases, i.e. less contention, decrease \( W_s \) */
26. \hspace{2em} \textbf{end if}
27. \hspace{2em} \textbf{end for}