Chapter 10
Modeling Vehicles Mobility for Connectivity Analysis in VANET

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Abstract The availability of more realistic road conditions and dynamics provides sound ground to study the issues of Vehicular ad-hoc Network (VANET). In this chapter a new heterogeneous traffic flow based mathematical model is presented, to gain the time and space dynamics of vehicles. To achieve more accurate and realistic data about road conditions, microscopic parameters of varying safety distance between the vehicles and vehicular length are considered in the model. The density dynamics under different road scenarios are calculated under the influence of these constraints with the use of a defined mathematical model. The model is able to capture the impact of road constraints such as traffic lights and road incidents, on the traffic flow. The concept of Vehicular Ad-hoc Networks (VANET) has given mankind opportunities for secure and safe journeys on the roads. VANET is defined as a subclass of Mobile Ad-hoc Networks which holds the characteristics of ad-hoc networks. However due to the dynamic road conditions, traffic flow theory concepts, mobility constraints, human behaviours and vehicular characteristics VANET exhibits different dynamics. These factors have strong influences on the VANET architecture from physical to application layers. This highlights different areas of interest in VANET for researchers to investigate. This study aims to capture the impact of traffic flow theory constraints on the vehicular density under the heterogeneous traffic flow on the road. The microscopic and macroscopic characteristics of vehicles moving on the roads are utilized for the improvement of VANET connectivity dynamics.

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10.1 Impact of Vehicle Mobility Pattern on VANET

In the area of vehicular research, the real life macroscopic and microscopic characteristics of vehicles are key issues to focus and analyse. The dynamic behaviour of vehicles on the road due to the road conditions, individual behaviour and surrounding environment affect its mobility pattern. In the vehicular ad-hoc network the timely distribution of information between the vehicles is the key issue. The moving patterns of vehicles impact the network communication as these structures define different road scenarios due to the implementation of traffic flow theory laws.The researchers have modelled the vehicle mobility in VANET by using the concept of different fields of science, engineering and mathematics. These mobility models use important road constraints and incorporate vehicular characteristics and traffic laws to define more realistic road conditions for the VANET. In [6] the influence of mobility patterns of vehicles on the performance of routing protocol in VANET is focused. They implemented the vehicle movement simulation tool SUMO [5] under NS2 simulator to capture more realistic traffic movements. They have presented the impact of traffic constraints such as density, speed and road structure on the performance of VANET. Considering the mobility of vehicles as a key factor to study the connectivity and evaluation of VANET performance [8] presented a concept of equivalent speed between the vehicles moving on the road. The study derived an analytical expression to relate the vehicular speed with connectivity under different mobility patterns and road scenarios.

The connectivity in vehicular ad-hoc network between different nodes has considerable effect under different road infrastructures and vehicle movement plans. The changing network topology of these kinds of networks is another factor which gives different values of connectivity. In real life vehicles are moving on different kinds of roads. For the vehicles moving on a highway, the researchers consider one way and two way moving patterns of vehicles. The vehicles changing speed, interaction with other arriving and departing vehicles are considered for connectivity dynamics.

The vehicles arriving rates are considered Poisson and Exponential in different research studies. The effect of neighbouring vehicles on the moving vehicle pattern is also considered for connectivity dynamics. In [7] the connectivity dynamics under different mobility models such as random way point and Manhattan mobility model are presented. The comparisons of important connectivity related constrains, under these models are presented by using simulated results for VANETs in an urban environment. When vehicles are moving in an urban road environment the microscopic constraints of traffic flow effect the vehicles mobility pattern.

10.2 Considering Vehicular Density for Analysing Connectivity in VANET

As the vehicles movement is effected by the road incidents and infrastructure, this dynamic change in vehicles conditions create a considerable impact on the vehicular density. The distribution of vehicles on the road needs to be considered as a random variable [19]. The vehicular density can be analytically observed for its effect on the connectivity. By utilizing the density dynamics of vehicles in [17] a clustering algorithm is implemented to improve the VANET performance. It provides a stable connectivity on the basis of existing larger groups of vehicles moving together known as a density based clustering algorithm.

The vehicular density depends on the changing road conditions. It goes up and down under the effect of traffic flow conditions. These characteristics of vehicular density provide an area of interest. To improve transmission capabilities of nodes in VANET for enhanced connectivity conditions the study [2] suggested the assignment of a dynamic transmission range for the nodes, on the basis of local density estimation defined by a technique called Dynamic Transmission Range Assignment (DTRA) algorithm. This algorithm considers the local traffic conditions as well as considering the density dynamics of the surrounding environment of a node, for the assignment of optimal transmission power to the nodes. The analysis of message propagation on the basis of asymmetric densities in VANET is presented by [1]. The study focuses the short range transmission technologies and local density on the opposite directions for improving connectivity.

The research considered the different road scenarios for finding density under dynamic road conditions. When the vehicles reached their max value of density they have the effect of jamming density on their speed. In the case of vexhicles moving with free flow the density value is significantly less which influences the connectivity. In real life road environments, there are different types of vehicles moving on the road. The length and speed variation of these vehicles create dynamic values of density. The platoon formation of vehicles on the road signals, turning points, incident points and junctions gives different dynamics of connectivity for analysis.

10.3 Implementation of Microscopic Parameter for Density Estimation of Heterogeneous Traffic Flow for VANET

When thinking about the safety of the passengers and safe journeys, the traffic flow needs to be governed by traffic codes on the roads. These traffic flow rules and regulations are defined by the traffic control authorities [24]. Researchers have introduced traffic flow models for analyzing the road conditions and vehicular behavior. The main focus was to achieve a maximum realistic traffic environment to carry out analytical and simulated data analysis for VANET. The microscopic and macroscopic parameters have been considered in many research studies to get realistic road conditions [14]. The traffic engineers define different relationships between these important parameters of traffic flow to present a new traffic flow model. These models consider linear relationship between speed and density, shockwaves effect due to different densities on streams of same flow, relating flow of traffic with fluid characteristics and the use of kinetic theory concept to define and relate two different flow regimes [9].

It has been observed that due to smaller safety distances between vehicles, accidents happen during the sudden stoppage of the front vehicle as a result of some road constraint. To avoid such situations, transport authorities have observed the law of safety distance between the vehicles very seriously. Several research studies have thus focused on this issue for obtaining secure traffic conditions. The authors in [10] worked on a project 'SASPENCE—Safe Speed and Safe Distance' to provide environment and, technology for the drivers to make their journeys safer by implementing a safe speed and safe distance concept.

The designing and implementation of vehicular ad-hoc network depends on the prevailing road conditions. The density dynamics are used to define transmission range and conditions for stable network connectivity. The use of density dynamics for the assignment of dynamic transmission range in vehicular ad-hoc network has been performed in these studies [3, 22].

The mobility of vehicles on the road is also considered to enhance the performance of vehicular ad-hoc network. The available models of traffic flow theory such as the fluid dynamic model and the car-following model have been used for representing traffic flow in many studies for vehicular ad-hoc network [4, 13]. Analytical modeling of vehicular ad-hoc network based on traffic flow models and density dynamics have been also reported [16, 26].

In this chapter the density of moving vehicles is achieved for different road scenarios and structures such as highway and the signalized urban road. The vehicular density is calculated with the use of fluid dynamic model having the effect of road conditions. A safety distance characteristic of the traffic flow has been implemented in a heterogeneous traffic environment using the Car-following model. Highway Code for safety distance between vehicles is introduced in the jamming density so that impact of jamming density on the velocity and density of vehicles can be analyzed. The implementation of these parameters provides more realistic traffic flow and road conditions.

10.3.1 Calculating Jamming Density for Heterogeneous Traffic Flow

It is evident from the studies of traffic flow theory that the microscopic parameters such as headway, gap and occupancy have an impact on the flow of traffic stream [11, 20]. In a real life scenario, traffic stream consists of different types of vehicles. The vehicles can be categorised as light traffic vehicles (LTV) such as cars and heavy traffic vehicle (HTV) such as buses and trucks. These vehicles have different structural and operating characteristics and exhibit different behaviour under the dynamic traffic flow conditions. Due to this heterogeneous nature of the leading vehicles, the following vehicle has to maintain specific safety distances from the front vehicle in accordance with the traffic safety laws. In a heterogeneous traffic flow, the constraints of headway and gap for the following vehicle become dependable on the characteristics of the leading vehicle. To observe the effect of heterogeneousness of vehicles structure on the dynamics of vehicular density, the traffic stream of two major types of vehicles i.e. cars and buses are considered. The vehicle motion is modelled with velocity profiles, having effects of leading vehicle conditions in term of density, length, and space headway. Vehicles of any type on the road at location 'x' and time 't' move forward with velocity $u_i(x,t)$', where $i = type$ of vehicle available on the road. This velocity can be deterministic or dependent on the front density and jam density. According to the Greenshield [18] in a car following environment, the speed, density and flow relation is given as in Eq. 10.1.

$$U(x,t) = u_f\left(1 - \frac{n(x,t)}{k_{jam}}\right) \tag{10.1}$$

where u_f is the free speed of vehicle, k_{jam} is the jam density, $n(x,t)$ is the vehicular density.

Introducing the safety distance of vehicle from the leading vehicle in heterogeneous traffic flow environment the jam density is given as in Eq. 10.2

$$K_{jam} = \frac{1}{L+h} \tag{10.2}$$

where L defines the length of a vehicle and h defines the safety distance of the specific vehicle from the leading vehicle. In a heterogeneous traffic environment due to the variable length of vehicles the space between the vehicles defined as headway/safety distance for following vehicle from the leading vehicle becomes a random variable. Thus $a - type$ of vehicles safety distance depends on the probability of other type of front vehicle and its characteristics. Let the h_{ab} is the safety distance for a-type of vehicle when the front vehicle is $b - type$. This h_{ab} satisfy that $\left(h_{ax(i)} > h_{bx(i+1)}u_{x(i)f} > u_{x(i+1)f}\right)$. The parameter P_b is the probability that the vehicle exists in front of a-type vehicle is of b-type. This state that the a-type safety distance is characterized as random variable and the safety distance h_{ab} will be given mean of the random variable h_{ab} i.e.

$$h_a = \sum_{b-1}^{N} p_b h_{ab} \tag{10.3}$$

For the jam density k_{jam} under random characteristic of length and safety distance the variables for $i - type$ vehicles, will be given as mean variables, so the variable L and h is given as

$$L = \sum_{i=1}^{N} p_i L_i \tag{10.4}$$

$$h = \sum_{i=1}^{N} p_i h_i \tag{10.5}$$

So the ja density for heterogeneous traffic flow can be define as

$$K_{jam} = \frac{1}{\sum_{i=1}^{N} p_i (L_i + h_i)} \tag{10.6}$$

By substituting the value of Jam density in Eq. (3.1)

$$U(x,t) = u_f \left(1 - \frac{n(x,t)}{\sum_{i=1}^{N} p_i (L_i + h_i)} \right) \tag{10.7}$$

This expression gives the speed of a vehicle by using the car following model which has the influence of length and safety distance of leading vehicles in heterogeneous traffic environment [23].

10.3.2 Using Deterministic Fluid Dynamic Model for Density Estimation of Heterogeneous Traffic Flow

Road traffic is characterized as fluid flow by the traffic engineers. This fluid like behaviour of moving vehicles on the road leads to represent different traffic models called continuum traffic flow models having characteristics of fluid dynamics. The fluid dynamic model represents traffic flow in the form of conservation law. It provides the traffic flow and density as a function of time and space. It relates the behaviour of traffic in the form of partial differential to represent parameters like flow, speed and density. The model presented in [25], we have considered heterogeneous traffic flow in a single-lane, one way, and semi-infinite highway environment. The location space is characterized with the interval $[0, \infty]$ the starting of the road is marked by boundary point 0, which is considered as spatial origin. The road is divided into a number of road segments represented by $r = 1, 2, 3, 4$ due to road intersections. The vehicles can join or leave the moving stream at these intersections called junctions. For the first segment of the road, the number of arrivals of all types of vehicles up to time t, is counted by an arrival process $(G(t)| - \infty < t < \infty)$, which is assumed to be finite with probability 1. This arrival process is characterized by external arrival rate function for all types of vehicles $\lambda(t)'$ which is non-negative and can be integrated. I have considered two types of vehicles that are car and bus. So the arrival rate for cars and buses is given by an external arrival rate function $\lambda_c(t)$ and $\lambda_b(t)$. The conservation equation relating important parameters of traffic flow is given as:

$$E^{+}(x,t) = N(x,t) + F(x,t) + E^{-}(x,t) \tag{10.8}$$

$N(x,t)$ as Total number of vehicles in location $(0,x)$, $F(x,t)$ Number of vehicles passing past position x, Whereas $E^{+}(x,t)$, $E^{-}(x,t)$ are vehicles arriving and departing rate. Implementing this conservation equation for cars and buses

$$E_c^{+}(x,t) = N_c(x,t) + F_c(x,t) + E_c^{-}(x,t) \tag{10.9a}$$
$$E_b^{+}(x,t) = N_b(x,t) + F_b(x,t) + E_b^{-}(x,t) \tag{10.9b}$$

For having partial differential equation form of conservation equation relating density, flow, arrival and leaving rate. We are differentiating Eqs. 10.9a and 10.9b by time and space [15]. Using operator on the Eqs. 10.9a and 10.9b.

$$\frac{\partial n_c(x,t)}{\partial t} + \frac{\partial f_c(x,t)}{\partial x} = e_c^{+}(x,t) - e_c^{-}(x,t) \tag{10.10a}$$
$$\frac{\partial n_b(x,t)}{\partial t} + \frac{\partial f_b(x,t)}{\partial x} = e_b^{+}(x,t) - e_b^{-}(x,t) \tag{10.10b}$$

According to the fundamental relation of traffic flow theory

$$f(x,t) = n(x,t) \times u(x,t) \tag{10.11}$$

Using Eq. 10.10 we have

$$\frac{\partial n_c(x,t)}{\partial t} + \frac{\partial [n_c(x,t) \times u_c(x,t)]}{\partial x} = e_c^{+}(x,t) - e_c^{-}(x,t) \tag{10.12a}$$
$$\frac{\partial n_b(x,t)}{\partial t} + \frac{\partial [n_b(x,t) \times u_b(x,t)]}{\partial x} = e_b^{+}(x,t) - e_b^{-}(x,t) \tag{10.12b}$$

These relations formed the one dimensional version of generalized conservation law for fluid motion in partial differential form representing cars and buses in heterogeneous traffic flow. By applying a chain rule and defining velocity as

$$u(x(t),t) = \frac{dx(t)}{dt} \tag{10.13}$$

After substituting the values from Eq. 3.8 we get the equation for finding density of two different type of vehicle.

$$\frac{dn_c(x(t),t)}{dt} = e_c^{+}(x,t) - e_c^{-}(x,t) - \frac{\partial u_c(x,t)}{\partial x} n_c(x(t),t) \tag{10.14a}$$
$$\frac{dn_b(x(t),t)}{dt} = e_b^{+}(x,t) - e_b^{-}(x,t) - \frac{\partial u_b(x,t)}{\partial x} n_b(x(t),t) \tag{10.14b}$$

$$N(x,t) = n_c(x(t),t) - n_b(x(t),t) \tag{10.15}$$

The Eqs. 10.14a and 10.14b have the effect of microscopic variables of headway and safety distance for different types of vehicles in the traffic stream and can be applied for finding total vehicular density with the use of Eq. 10.15 having effect of dynamic road conditions [21].

We have introduced a velocity profile from a car following the model defined in Eq. 10.1 in Eqs. 10.10a and 10.10b for density estimation using fluid dynamic model. The algorithm for simulation is run iteratively for getting speed on current time for all locations. The differential equation from fluid dynamic model is then solved for density by using the velocity data at time 't' for all locations 'x'. The effect of heterogeneousness in fluid dynamic model is introduced by using the new value of jamming density in Eq. 10.7 and giving speed of vehicle (i) in heterogeneous environment.

10.4 Numerical Analysis for Highway Traffic Flow

We assume that no vehicle is joining or leaving the highway at junctions so that the continuous flow of vehicles can be achieved on the road. The vehicles arrive only at location 0 at a constant arrival rate $\lambda(t) = 50$ vehicles/min. The constant arrival of 50 vehicles/min creates enough traffic streams to gain vehicular density. This arrival rate is further divided in arrival ratio of two types of vehicles, cars and buses. The arrival rate for cars and buses is defined as $\lambda_c(t)$ and $\lambda_b(t)$ having different arriving ratios for heterogeneous arrival. The arrival rate for a car and a bus is changed for a different simulation run to create scenarios to implement the different traffic flow conditions. We consider that initially there is no vehicle on the road when traffic starts. So $n_c(x, 0) = 0$ and $n_b(x, 0) = 0$ for all 'x' belongs to 'X' where 'X' is location space in km. The initial velocity for all vehicles as calculated from Eq. 10.1 at ($t = 0$) will be the mean free speed $u_f = 1$ km/min.

- Finding Jamming density for car only case.

The jamming density is calculated for car only case by using the two different formulas. (i) ($kjam = 1/lc$) which only considered the length of vehicle so for car only case $lc = 4$ m. (ii) ($kjam = 1/lc + hc$) having safety distance between the vehicles and length of considered vehicle. For car only case, lc = 4 m and hc = 4 m and 12 m for two different road scenario. I introduced a traffic constraint on the highway between location 3–7 km to capture the effect of jam density and velocity change on vehicular density. The impact on vehicular density between these two locations is later presented at different time intervals. The velocity field $U_i(x, t)$ is calculated from Eq. 10.1 for cars only case and from Eq. 10.7 for heterogeneous case for all $x \geq 0$ when $t \leq 30$ or $t > 45$ min. For $30 < t \leq 45$ min, the velocity field is calculated as:

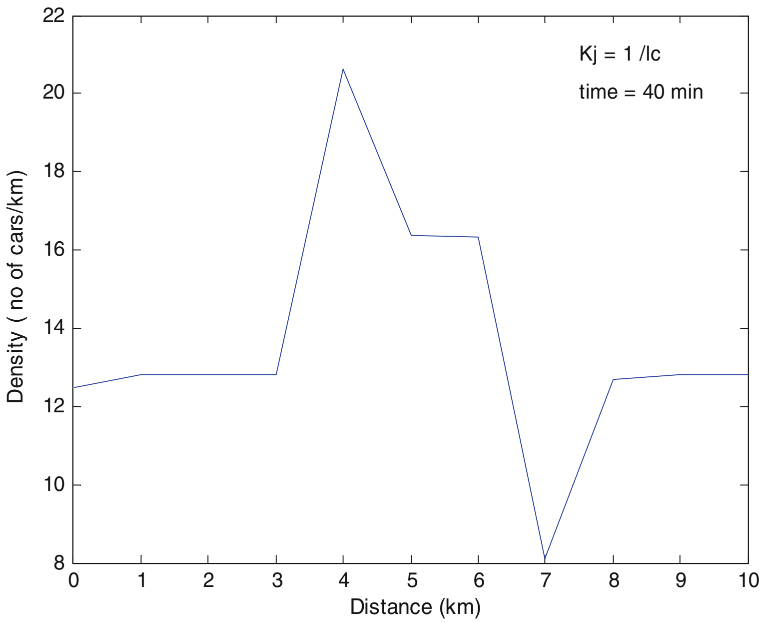

Fig. 10.1 The Vehicular Density for car only case with $K_j = 1/lc$

$$U_i(x,t) = \begin{cases} U_i(x,t) & \text{if } x \leq 3 \\ U_i(x,t) - (\frac{U_i(x,t)}{2}) & \text{if } 3 < x \leq 4 \\ \frac{U_i(x,t)}{2} & \text{if } 4 < x \leq 6 \\ U_i(x,t) + (\frac{U_i(x,t)}{2})(x-6) & \text{if } 6 < x \leq 7 \\ U_i(x,t) & \text{if } x > 7 \end{cases} \tag{10.16}$$

The Fig. 10.1 shows the density for cars on the highway at time 40 min. The density dynamics of vehicles show dynamic behaviour between locations 3–7 km due to a sudden constraint at this location. The change in velocity during this interval affects the vehicular density. As the vehicles move on, the density starts building up.

The vehicular density falls down due to the sudden stop of traffic flow and goes back to constant rate after certain distance. In Fig. 10.2 with the introduction of safety headway between the cars, the jam density is calculated under car length and safety distance constraints. The increase in safety distance affects the velocity as indicated in Fig. 10.2. The velocity graph is achieved for two different safety distances between the cars i.e. 4, 12 m. The variable safety distances between the cars define two different traffic flow conditions. The impact of road constraints on the velocity is expressed with the decrease of velocity profile. As a result of constraint on the road, the velocity decreases and density changes sharply at location 4 m.

The increase in safety distance provides smooth flow of traffic and shows increased density dynamics less than 12 m safety distance case as compared to 4 m case, reflected in Fig. 10.3. The vehicular density shows dynamic behaviour between the distances 3–7 km under the effect of road constraint.

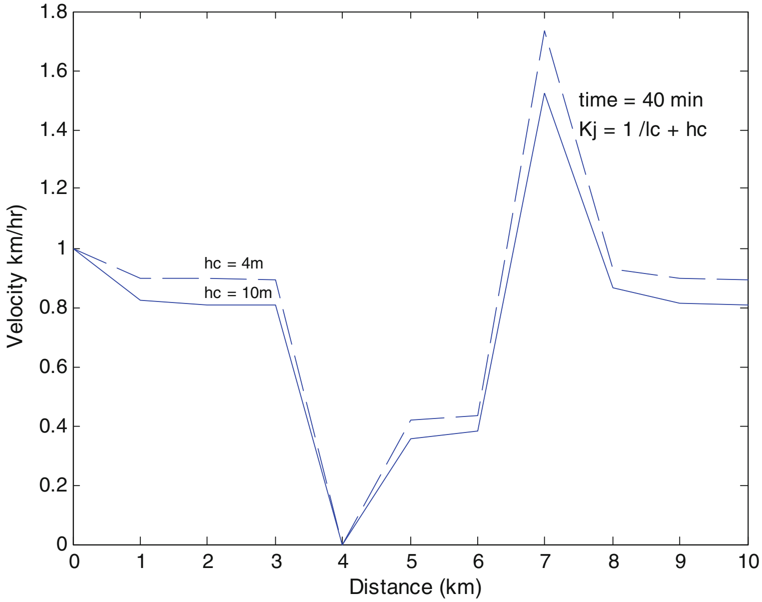

Fig. 10.2 The Vehicle Velocity for car only case with jamming density defines as $K_j = 1/(lc + hc)$

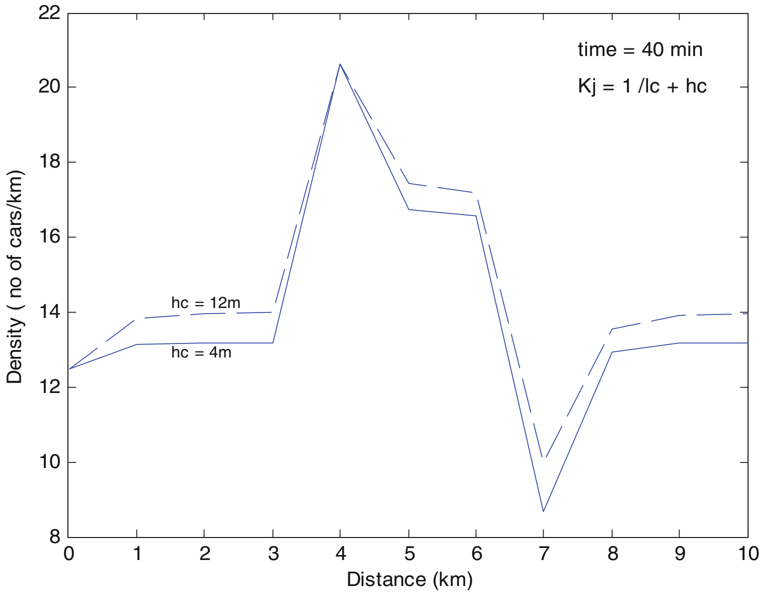

Fig. 10.3 The Vehicle Density for car only case with jamming density defines as $K_j = 1/(lc + hc)$

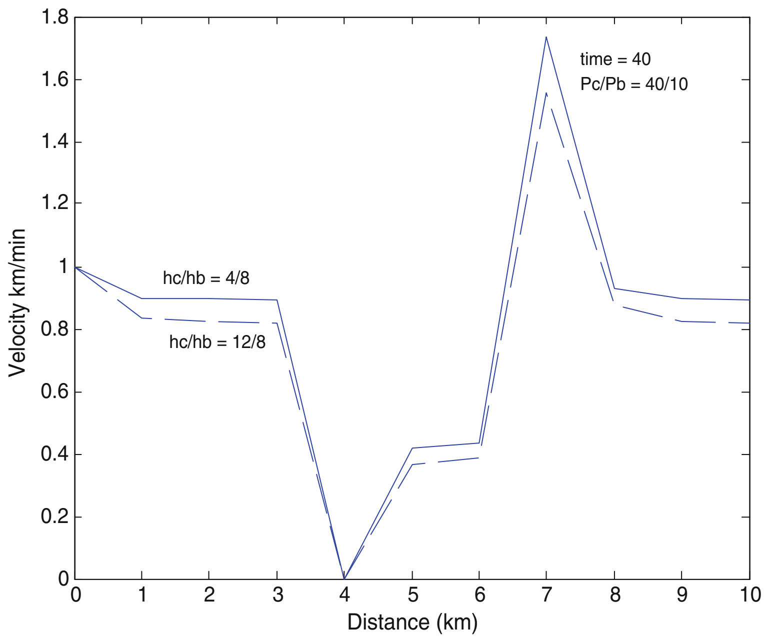

Fig. 10.4 The Vehicle Velocity for cars and buses case and buses case having effect of safety distance in K_j with cars in excess ratio

- Finding Jamming density for heterogeneous traffic flow case

The jam density for heterogeneous traffic flow considering cars and buses is calculated by the Eq. 10.7. This equation has influence of length, safety distance and varying arrival ratio for cars and buses. The external arrival rate for car $\lambda_c(t)$ and bus $\lambda_b(t)$ is considered as $a = \lambda_c(t)/\lambda_b(t) = 40/10$ for Figs. 10.4 and 10.5 and $b = \lambda_c(t)/\lambda_b(t) = 10/40$ for Figs. 10.6 and 10.7. The two different arriving ratios of cars and buses and the safety distance ratio between the car and bus 'hc/hb' are considered to analyse vehicular density dynamics under my mobility model for different road and traffic flow situations. In Figs. 10.4 and 10.5 the $h_c/h_b = 04/08$ and $h_c/h_b = 12/08$ defines the changing safety distance between cars and buses, having 04 and 12 m safety distance between cars whereas keeping the bus safety distance at 08m constant as buses are following the same moving pattern on the road. For the Figs. 10.6 and 10.7 to observe the effect of constant safety distance between the cars on the traffic flow the safety distance between buses is changed. The ratio for car and bus safety distance is defined as $h_c/hb = 08/16$ and $h_c/h_b = 08/04$ having fixed car safety distance and changing safety distance for buses such as 16 and 4 m. In both cases the car length 'lc' is fixed as 4 m and bus length 'lb' is kept at 10 m. The effect of these changes in arriving and safety distance ratios on vehicular velocity and density is shown in Figs. 10.4, 10.5, 10.6 and 10.7. The safety distance varies for different types of vehicles on the road, therefore the ratio 'hc/hb' are varied to

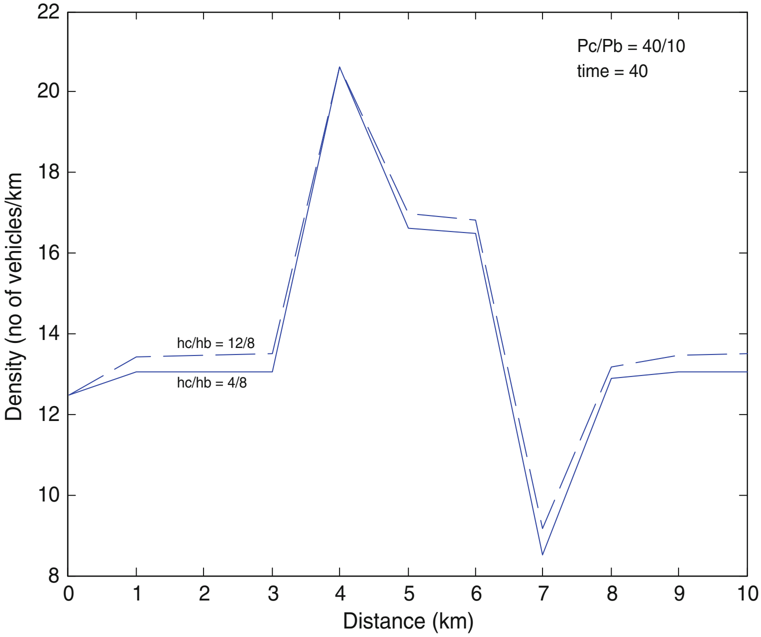

Fig. 10.5 The Vehicle Density for cars and buses case and buses case having effect of safety distance in K_j with cars in excess ratio

get the effect of changing road conditions on vehicular density. These results shows that at time 40 min velocity starts decreasing between locations 3–7 km due to a constraint on the highway in all the cases. The flow conditions under excess number of small vehicles with optimal safety distance provide better results as compared to long vehicles. The arriving ratio and safety distance between vehicles affects the vehicular density. The impact of a microscopic parameter in both the car only, and the car and bus case is captured. The traffic conditions can be manipulated with the proper use of microscopic parameter of safety distance.

10.4.1 Introducing Impact of Leading Traffic Flow in Velocity

In a heterogeneous traffic environment due to the different types of vehicles and their characteristics, the traffic flow exhibits dynamic behaviour. The leading vehicles impact the traffic pattern, which influence the vehicular density on the road. To observe the effect of leading traffic conditions the concept of front density profile is introduced in the previous study [12]. To achieve a realistic traffic condition and density profile, in our work I have introduced the effect of heterogeneous traffic

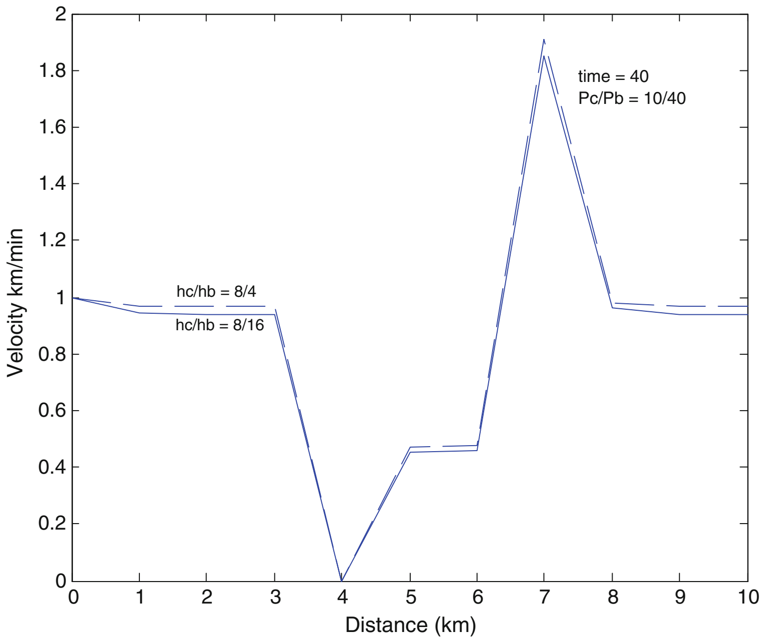

Fig. 10.6 The Vehicle Velocity for cars and buses case and buses case having effect of safety distance in K_j with cars in excess ratio

environment in the front density. As the front density is increased due to traffic signal implementation, the density dynamics of the road for that region is also affected. By using Eq. 10.7 and introducing front density as Δx the velocity equation under front density will be given as

$$U_i(x, t) = u_f\left[\frac{(1 - N_T)(x + \Delta x, t)}{\sum_{i=1}^{N} p(L_i + h_i)}\right] \tag{10.17}$$

10.4.2 Density Estimation for Heterogeneous Traffic under different Safety Conditions in Signalized Road Structure

In this model we considered heterogeneous traffic flow in a single-lane, one way, semi-infinite signalized road in an inner-city environment. The road is divided into the number of road segments represented by $r = (1, 2, 3, 4 \ldots.)$ controlled by traffic lights installed at the point of intersection. We assume that no vehicle is joining or leaving the road at intersections. The vehicles arrive only at location 0 at a constant rate $\lambda(t) = 20$ vehicles/min this includes all type of vehicles. For the heterogeneous

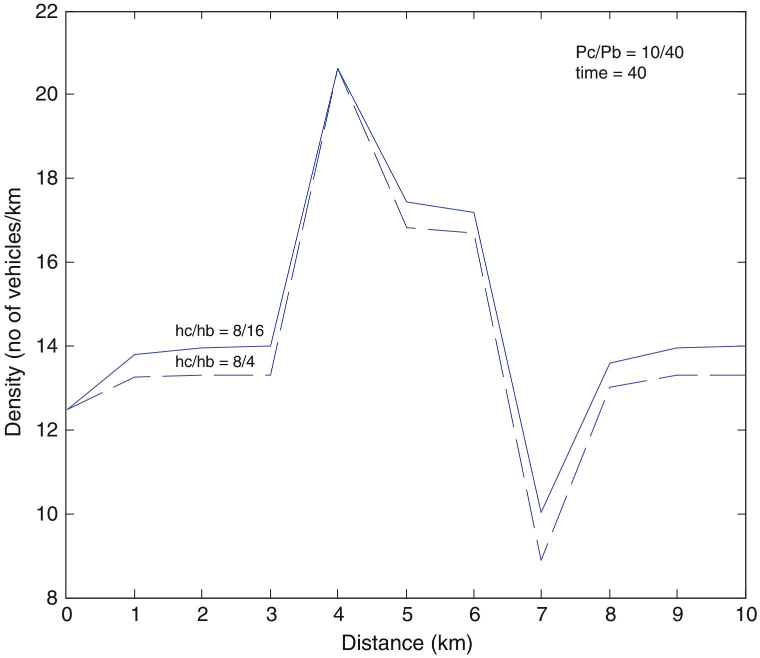

Fig. 10.7 The Vehicle Density for cars and buses case and buses case having effect of safety distance in K_j with cars in excess ratio

traffic flow the arrival rate for cars and buses is defined as $\lambda_c(t)$' and $\lambda_b(t)$ having different arriving ratios for different road scenarios. We consider that initially there are no vehicles on the road when traffic starts. So $n_c(x, 0) = 0$ and $n_b(x, 0) = 0$ for all x belongs to X where X is location space in km. The initial velocity for all vehicles as calculated from Eq. 10.1 at $(t = 0)$ will be the mean free speed $V_f = 1$ km/min. On the road at the distance of 4 km, we have introduced a traffic light to capture the effect of vehicles interaction due to the safety distance and front density of the road traffic on vehicular density. The velocity field $U_i(x, t)$ is calculated from Eq. 10.1 for cars only case and from Eq. 10.17 for heterogeneous case under front density profile. During the red traffic light period, traffic is stopped for 4–4.5 min for 30 s. For the implementation of a road junction, an extra 0.012 Km distance is considered before the traffic light. During the stopping period, the velocity profile for road traffic is calculated as:

$$U_i(x,t) = \begin{cases} U_i(x,t) & \text{if} \quad x \leq 3.98 \\ (\frac{U_i(x,t)}{0.02})(4-x) & \text{if} \quad 3.98 < x \leq 4 \\ 0 & \text{if} \quad 4 < x \leq 4.012 \\ (\frac{U_i(x,t)}{0.02})(x-4.032) & \text{if} \quad 4.012 < x \leq 4.032 \\ U_i(x,t) & \text{if} \quad x > 4.032 \end{cases} \tag{10.18}$$

The traffic condition on the road is dynamic due to the changing arriving rates for different types of vehicles. Due to these arriving patterns the safety distance between the vehicles is also affected. In Figs. 10.8, 10.9 and 10.10 to capture the effect of heterogeneousness traffic flow on density for cars and buses case I have assumed 20 vehicles such as the external arrival rate for two types of vehicle car and bus is given as: Car $(\lambda_c(t)) = 12/20$ and bus $(\lambda_b(t)) = 08/20$ The different arriving ratio for car and bus creates an impact of different vehicular characteristics due to their types on the vehicular density. For the three different road scenarios under the influence of increasing safety distance between the cars, we have considered three different safety distances between the cars (sfdc) such as

- $2 \times$ car-length for case (a) in Fig. 10.8
- $3 \times$ car-length for case (b) in Fig. 10.9
- $4 \times$ car-length for case (c) in Fig. 10.10
- The safety distance for buses is fixed as 0.012 Km as they are following the same pattern.

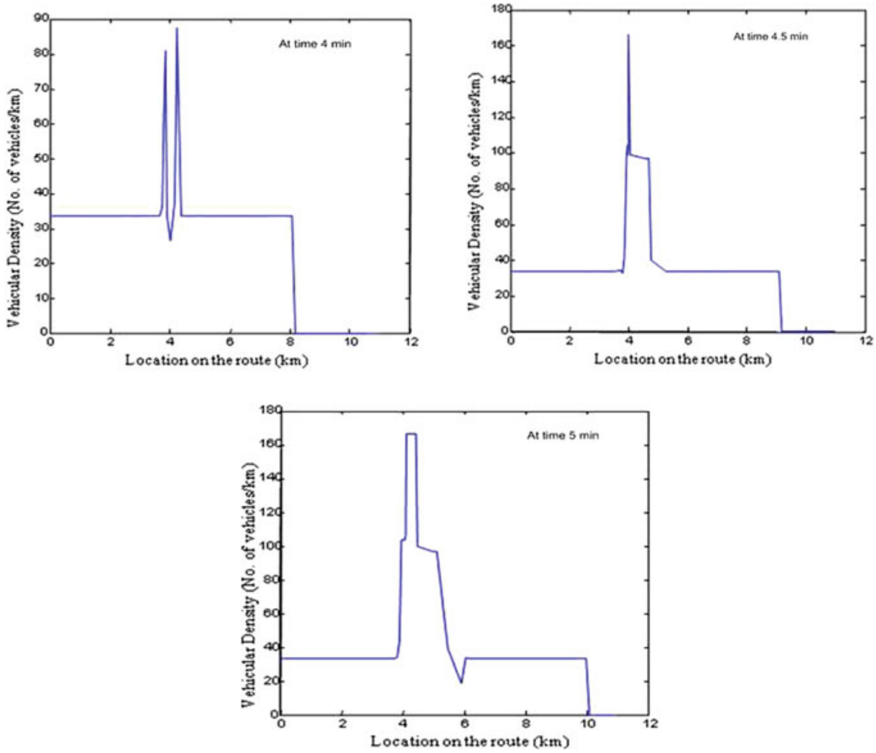

Fig. 10.8 Vehicle Density on the signalized road at time 4 min, 4.5 m and 5 min under safety distance $= 2 \times car - length$

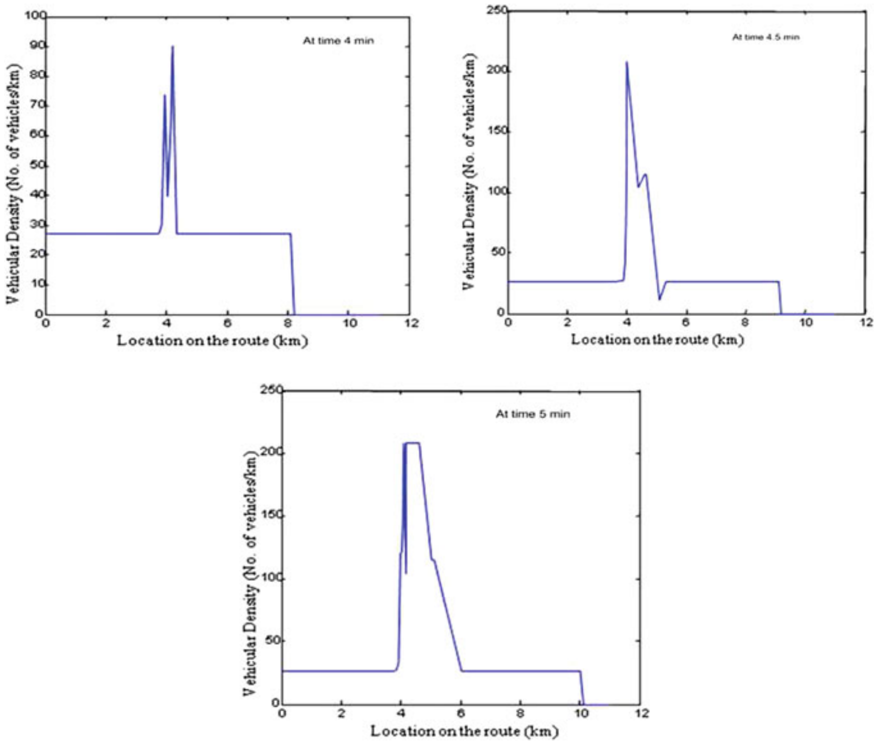

Fig. 10.9 Vehicle Density on the signalized road at time 4 min, 4.5 m and 5 min under safety distance $= 3 \times car - length$

As the outcome of the fluid dynamic model through the solution of differential equations provides vehicular density, whereas for the analysis of connectivity dynamics we need a number of vehicles in the covered area. This required data is achieved by the integration of vehicular density. The expression is given as: The mean number of vehicles within the covered distance (x1, x2) is

$$E[N_T(x_1, x_2, t)] = \int_{x_1}^{x_2} n(x, t)dx \tag{10.19}$$

In Fig. 10.8 the effect on vehicular density under the road condition such as: Safety distance between the $cars = Sdfc = 2 \times car - length = 8$ m where car length = 4 m is captured at time 4, 4.5 and 5 min. As the traffic flows on the road the velocity profile is built under the influence of safety distance and front density of road traffic. The calculated velocity is affecting the road density due to the iterative process as it is used by the differential equation for density estimation in Eqs. 10.14a and 10.14b.

At the time 4 min due to the traffic signal the vehicle platoon formation is created which lasts for a stopping period shown as time 4.5 min in the graph. As the light

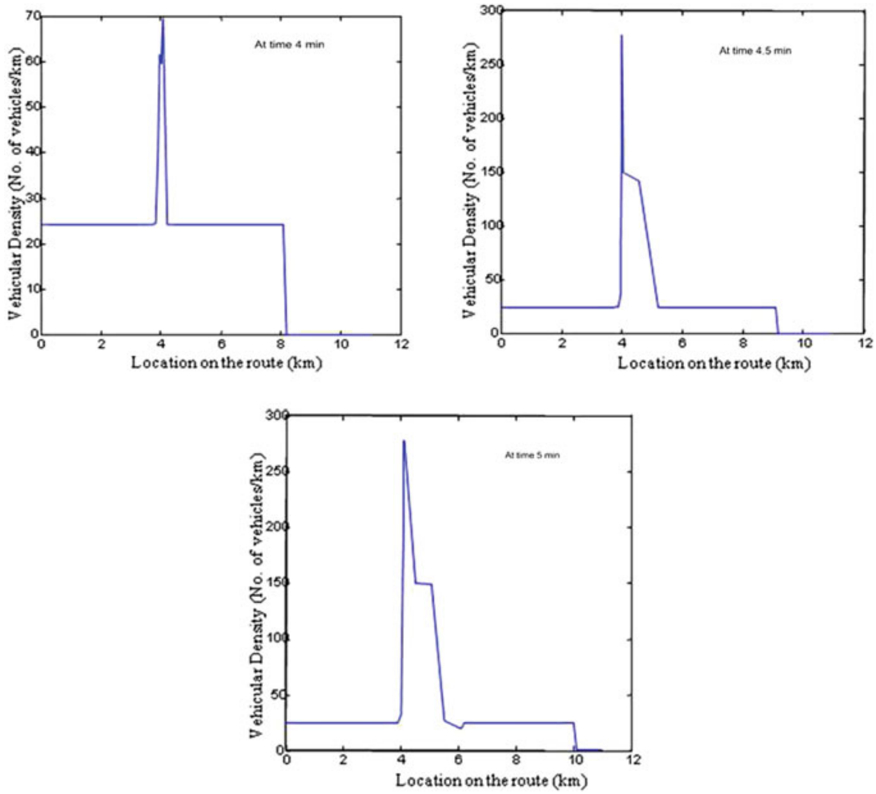

Fig. 10.10 Vehicle Density on the signalized road at time 4 min, 4.5 m and 5 min under safety distance $= 4 \times car - length$

goes green the vehicles disperse and the density curve shows normal behaviour after the time of 5 min.

In Fig. 10.9 the density dynamics are captured at different times during the traffic flow under assumed safety distance between cars defined as: Safety distance between the $cars = Sdfc = 3 * car - length = 8$ m where car length $= 4$ m The density graph starts building at 4 min at location 4 Km along the road due to the traffic signal implementation as the traffic light turns green the vehicles fast dispersion make an impact on vehicular density which is shown at time 4.5 and 5 min.

For the Fig. 10.10 the safety distance between the cars is assumed as: Safety distance between the $cars = Sdfc = 4 \times car - length = 16$ m where car length $= 4$ m.

The vehicular densities under these assumptions are achieved at time 4, 4.5 and 5 min. The variation in safety distances impact the traffic flow on the road. A smooth vehicular density peak is built at 4 min when red light is in operation. The vehicles dispersed with the green light at 4.5 and at 5 min traffic flow makes the density graph at a constant level.

The vehicular density under $2 \times car - length$ safety distance shows high formation of vehicle platoon. The red light implementation stops vehicles at 4 min and creates vehicles stoppage.

The formation and dispersion of vehicles on the road is well captured at 5 min. The dissipation of vehicles during safety distance $2 \times car - length$ is smooth. Due to an adequate number of vehicles on the road by keeping less safety distance between them, platoon formation is captured more clearly as compared to other cases when safety distance between the cars is 3*car-length and 4*car-length.

10.5 Summary

The traffic mobility model presented in this chapter is able to capture more realistic traffic flow conditions for the different road scenarios. With the use of the fluid dynamic model and the implementation of key microscopic parameters of safety distance and vehicular length under heterogeneous traffic flow environments the achieved vehicular densities provide more realistic data as compared to previous studies. The availability of different types of vehicles is considered in a mathematical model by using partial differential equations to find the total vehicular density. The influence of important constraints of vehicular structural characteristics and moving patterns on the density is focused in further study. The impact of microscopic parameters of safety distance and leading vehicles on vehicular density and velocity is captured. The mobility of vehicles can be manipulated with the optimal use of safety distance between the vehicles. The mobility model also provides useful data for further different VANET analysis.

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