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# Zone Based Traffic Adaptive Mechanism for Traffic Light Control using VANET

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**Abstract:** Nowadays, the problem of traffic congestion becomes severe in almost all the countries of the world. Waste of time and money, loss of human life and negative impact on the environment are some adverse effects of traffic congestion. Currently, to minimize the impact of traffic congestion, different traffic light control mechanisms are deployed but these mechanisms are not capable of handling the problem of increased traffic efficiently. Researchers across the globe are working on an Intelligent Transport System which aims to provide hassle-free traffic movement. Many researchers have proposed dynamic solutions for controlling traffic light considering traffic density and traffic velocity within the ready or green area but almost all the researchers have taken a static value of this ready or green area and hence these solutions are performing well for specific traffic scenarios but not for all the scenarios. In this paper, a novel Zone based traffic adaptive traffic light control mechanism is proposed which efficiently calculates optimal green phase time and cycle time for a traffic light. In the proposed mechanism, for calculating the optimal value of green phase time and cycle time, ready or green area is divided into different zones. Each zone is allocated a specific multiplying factor (weight) and zone wise real-time traffic density is collected using VANET. For all the edges, priority is calculated based on the multiplying factor of the zone and traffic density within that zone. The edge with maximum priority will be allocated a green phase first. To evaluate the performance of the proposed system, a simulation testbed is prepared using SUMO traffic simulator. The simulation result shows that the proposed mechanism significantly minimizes the waiting time compared to the other dynamic mechanisms. To determine optimal value of number of zones, the performance comparison considering two, three and four zones is also presented.

**Keywords:** Intelligent Transport System, Traffic light control mechanism, VANET

## 1. INTRODUCTION

Almost two third of the world's population is expected to live in urban areas by 2050 and hence automobile and infrastructure industries see rising strain [1]. In India, during the financial year 2017-18, 16.2% and 4.99% growth rate is observed in passenger and commercial vehicle segments respectively [2]. Similar kind of rising trend is observed for automobile industries which resulted in the problem of traffic congestion. Traffic congestion causes delay, inconvenience and economic losses to drivers [3]. According to the Urban Mobility Scoreboard 2015, in the USA three billion gallons of fuel was wasted for traffic congestion and travelers get stuck in their cars for almost seven billion extra hours [4]. To address challenges related to traffic congestion, various Traffic Light Control (TLC) mechanisms are implemented. TLC mechanisms are broadly categorized as statically timed (traditional) and traffic adaptive [5]. As traffic density varies with time, the traffic adaptive TLC mechanism is proved to be more efficient for the objective like minimizing average waiting time and maximizing intersection throughput [6].

The primary challenge of traffic adaptive mechanism is to collect real-time traffic information like traffic density, traffic speed, distance from the intersection, etc. In literature, different sensor based and message based approaches are presented by researchers for collecting real-time traffic density [7]. Almost all the approaches calculate traffic density between signalized intersection and a point located at a predefined distance known as Ready Area (RA) [8]. Traffic information like density and average speed within the RA are two main parameters for calculating phase and cycle time of traffic light. Hence for variable traffic scenarios, predetermined or misjudged RA results in an inefficient schedule for traffic light which increases waiting time of vehicles.

This paper proposes a more effective way of calculating phase and cycle time. As different regions in RA can have different vehicle density, a novel TLC mechanism is proposed in which RA is logically categorized in different zones. Each zone has its weight factor which is used to calculate priority weight for an edge. Since RA is divided

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into zones, the proposed mechanism is capable of coping with variable traffic scenarios. Average waiting time and intersection throughput are the performance parameters used for evaluation.
Major research contributions of this paper are:

- Proposed a novel Zone based TLC mechanism to decide optimal phase and cycle time for traffic light using VANET.
- Evaluated the performance of the proposed mechanism for a single traffic intersection and a 9.5 km long corridor having five traffic intersections.
- Simulated more realistic traffic scenario by considering different vehicle types like heavy motor vehicle and light motor vehicle.
- Tested the performance of the proposed TLC mechanism considering two, three and four zones.

The rest of the paper is organized as follows. The related work available in the literature is presented in Section 2. Problem scenario is explained in Section 3. Section 4 presented the proposed TLC mechanism. Simulation environment, result and discussion are presented in Section 5. Finally, Section 6 concludes the paper.

## 2. RELATED WORK

Various TLC mechanisms have been proposed by different researchers with the aim to minimize waiting time of the vehicles at signalized intersection and increase throughput of signalized intersection. The state-of-the-art taxonomy of TLC mechanism is presented in Figure 1. Traffic density is one of the crucial parameters for traffic adaptive TLC mechanism and hence, determining accurate value of traffic density is indeed essential. In literature, various sensing and communication technologies are presented to calculate real-time traffic density, such as (i) Force resistive sensor (ii) Inductive loop (iii) RFID (iv) Video camera (v) Wireless Sensor Network (WSN) (vi) Vehicular Ad-hoc Network (VANET). In [9][10][11][12], authors have used inductive loop detector for calculating traffic density whereas authors of [13][14] have used force resistive sensors. Some researchers [15][16][17] have taken advantage of already deployed video cameras and apply different image processing concepts to extract traffic information. The biggest challenge for all these on-road sensors is their initial setup and repair. Researchers [18][19][20] have explored RFID for traffic sensing but this technology suffers from the problem of limited coverage. Researchers in [21][22][23][24] have used WSN to provide an energy efficient solution for maximizing message delivery and minimizing end-to-end delay given a minimum number of sensor nodes and mobile sink nodes. Many researchers have explored VANET [25][8][9][26][27][28] as an option to on-road sensors for calculating traffic density. With the option of different types of communication like V2V, V2I and I2V, VANET is considered as one of the best choices for collecting different traffic parameters [29]. It has touched almost all the limitations of aforementioned technologies but maintaining secure communication is still a challenge. Table I summarizes usage and limitations of aforementioned technologies.

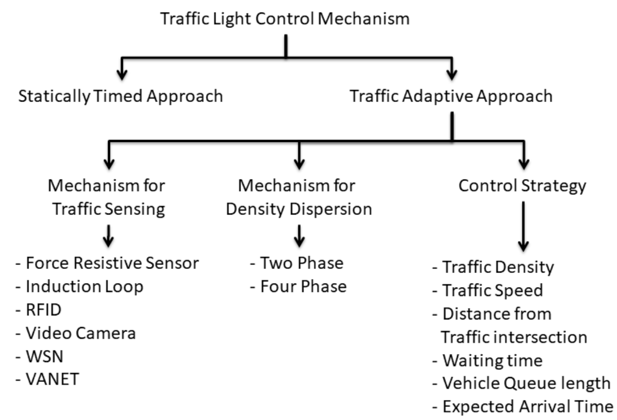


Figure 1. State-of-the-art taxonomy for TLC mechanism

Principles of traffic signal design suggest two approaches for density dispersion namely two phase system and four phase system. Two phase system proves to be an efficient system when for all the edges, through traffic has more traffic density compared to turning traffic. If traffic density marginally varies among both the traffic then four phase system is more efficient. Considering this fact and traffic pattern in urban areas, researchers in [10][11][13] have proposed TLC mechanisms using a four phase system. These proposals have given priority to the edge with maximum traffic density whereas in [25][8] M. B. Younes et al. have further classified four edges into eight different traffic flows and the traffic flow with highest traffic density is given priority along with other non-conflicting traffic flow to minimize waiting time of the vehicles.

For minimizing waiting time of traveling vehicles at traffic intersection, different control strategies have been adopted by researchers. Jianqi Liu et al. [9] have considered only traffic density on the edge to schedule the traffic light whereas M. Bani Younes et al. [25] have considered traffic speed and time required to cross intersection along with traffic density in RA. In [30], X. Liang et al. have considered waiting time to allocate phase duration effectively whereas Anuj Sachan et al. [31] have considered average queue length along with the waiting time. In [11], parameters like count of waiting vehicles, time required to cross an intersection and safety time are considered for deciding the cycle time of traffic light. Authors in [8][32][33] have used the distance of the last vehicle in RA from traffic intersection and traffic speed for calculating green phase time. K. Pandit et al. [26] have worked on vehicle platoons and determined expected arrival time of platoon at traffic intersection based on distance and speed of platoon. Authors have calculated green phase time using the

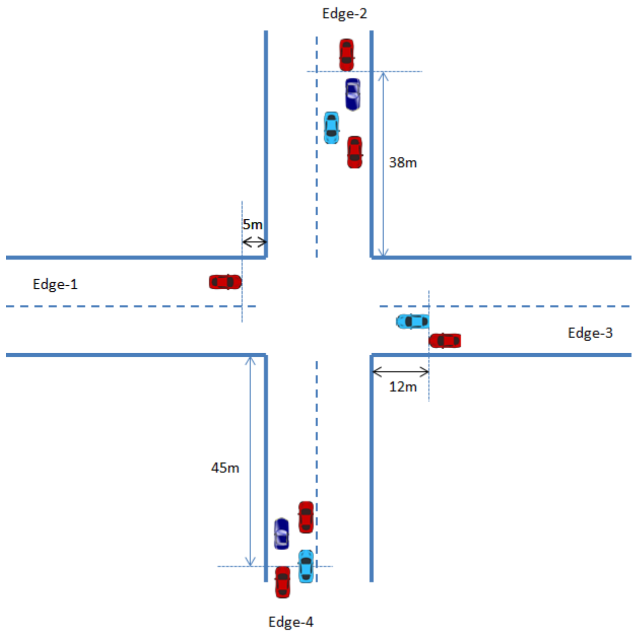


Figure 2. Problem Scenario

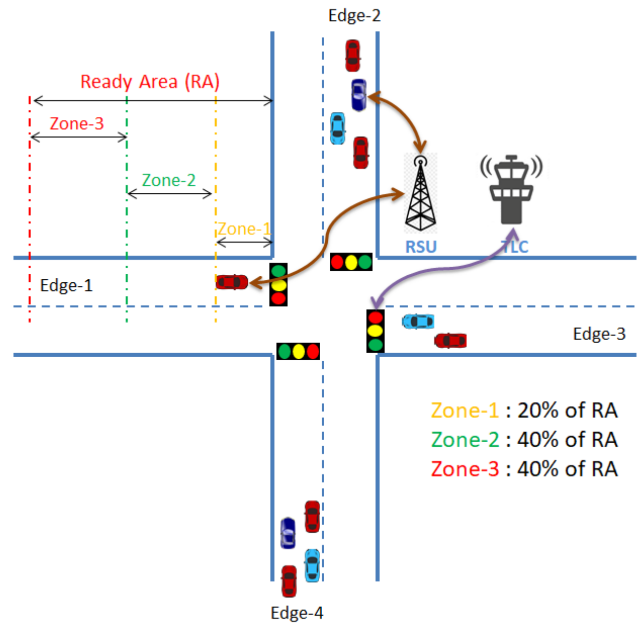


Figure 3. Four-leg Signalized Traffic Junction with Proposed approach

value of expected arrival time. Considering the principles of traffic signal design, Noori et al. [27] have used saturation headway and start-up lost time along with traffic density, distance and speed to determine phase time and cycle time.

## 3. PROBLEM SCENARIO

According to Webster's method, to minimize delay at signalized traffic intersection, green time utilization should be maximized. Green time utilization is the proportion of the total green phase time actually utilized by vehicles to cross signalized traffic intersection. Maximum green time utilization can be ensured if the value of green phase time is optimal and time to start the green phase is accurate. Misjudging the value of any of these parameters can lead to an increase in waiting time. Figure 2 demonstrates a scenario where all the four edges have vehicles available in their RA. All the edges will be given a green phase according to the descending order of their traffic density. To calculate green phase time, distance of last travelling vehicle within RA and traffic speed (8.33 m/s) is considered. All the calculated values are presented in Table II.

From Table II, we can see that for Edge-2, allocated green phase time is 5 seconds, out of which only 2 seconds are utilized by vehicles and hence, green time utilization is 78% for this traffic light cycle. Moreover on Edge-3 and Edge-1, vehicles need to wait for a longer duration though they can pass traffic intersection in almost no time. This is due to the fact that only traffic density on a particular edge is considered for assigning green phase but the distance of the first vehicle from the signalized traffic intersection is not taken into account and hence, inappropriate assignment of green phase occurs. The chances of inappropriate assignment can be reduced by dividing RA into multiple subareas known as zones based on distance from signalized traffic intersection. This paper proposes a novel approach to determine optimal traffic light schedule by dividing RA into multiple zones.

## 4. PROPOSED TLC MECHANISM

Architecture of the proposed TLC mechanism is presented in this section. Figure 3 shows the most generic signalized traffic intersection with eight edges and each edge contains two lanes, one for through traffic and other for turning traffic. Ready Area (RA) on each traffic edge is logically divided in three zones to prepare an efficient traffic light schedule. Vehicles in the first 20% of the RA can reach at traffic intersection immediately so that portion of RA is considered as zone-1. Vehicles in the next 40% of the RA require moderate time so this area is considered as zone-2 and the remaining 40% of the RA is considered as zone-3 since vehicles in that portion need more time compared to other two zones. Traffic lights switch between two signals, green to go and red to stop. The proposed mechanism is able to handle both light and heavy motor vehicles with varying length and speed. To minimize the average waiting time of vehicles at signalized traffic intersection, following elements are implemented in proposed mechanism.

- ***Road Side Unit (RSU)***: For traffic adaptive TLC mechanism, it is mandatory that signalized traffic intersection need to be observed continuously and hence, VANET enabled RSU is deployed at each traffic intersection. It periodically broadcasts "Density Request" (DR) message using Infrastructure to

TABLE I. APPROACHES USED FOR TRAFFIC SENSING

| Approach | Usage | Limitations |
|---|---|---|
| Force Resistive Sensor[9][10] Inductive loop detector[13][14] | Vehicle is detected when it passes through the sensor/detector. Sensor sends sensed data to TLC using wired medium which will be used to adjust phase time of traffic light. | Installation, maintenance and replacement is difficult due to constant traffic movement. Chances of damage in hardware are high due to construction or maintenance work which leads to interruption in sensing. |
| RFID[18][19] | Vehicle is detected when it passes within the range of RFID receiver. RFID receiver transfers data with TLC using wired or wireless (ZigBee) medium. | Detection accuracy is dependent on the type of tag (Active/Passive) used. Parallel movement of more vehicles can lead to inaccurate result. Detection of vehicle having high speed is challenging. |
| Video Camera[15][16] | Detection of vehicle is based on different image processing and artificial intelligence techniques. More vehicular attributes can be extracted. | High computing capacity is required due to the inclusion of image processing and artificial intelligence. Shadowing problem can affect the accuracy due to the existence of heavy duty vehicles. Detection accuracy is also dependent on weather. |
| Wireless Sensor Network[23][24] | Sensor nodes are distributed across the roads which collect traffic data once vehicles enter in their coverage. Collected traffic data is forwarded to TLC using intermediate nodes. | Implementation can be complex for large scale deployment. Maintenance of sensor nodes can be difficult and costly. Ensuring security in WSN is challenging. |
| VANET[25][8] | Vehicles (OBU) equipped with transceiver collect vehicular data within the coverage with the help of DSRC. TLC receives vehicular data using Vehicle to Vehicle (V2V) or Vehicle to Infrastructure (V2I) communication. Different vehicular attributes like speed, type, length, heading, etc can be easily extracted which can be used for deciding an efficient phase time. | For very low density scenarios, the communication between vehicle and TLC can be interrupted due to unavailability of carry forward node. Ensuring security in VANET is challenging. Highly dynamic topology due to constant vehicle movement. |

TABLE II. CALCULATED VALUES OF DIFFERENT PARAMETERS FOR PROBLEM SCENARIO

| EdgeId | Traffic density | Distance of last vehicle from traffic intersection (m) | Green phase time (sec) | ETA at traffic intersection | Cycle duration (sec) | Green time utilization (sec) | Waiting time (sec) |
|---|---|---|---|---|---|---|---|
| 2 | 4 | 38 | 5 | 3 | 0-5 | 2 | 0 |
| 4 | 4 | 45 | 6 | 5 | 5-11 | 6 | 0 |
| 3 | 2 | 12 | 2 | 1 | 11-13 | 2 | 10 |
| 1 | 1 | 5 | 1 | 1 | 13-14 | 1 | 12 |
| | | Total | 14 | - | - | 11 | 22 |

Vehicle (I2V) communication to calculate real-time vehicle density on each road.

- ***Vehicles***: VANET enabled vehicles have an On Board Unit (OBU) through which vehicles can communicate with other vehicles or infrastructure (RSU). Upon receiving "Density Request" message from RSU, vehicle sends "Vehicle Response" (VR) message in response.
- ***Traffic Light Controller (TLC)***: TLC is installed at each traffic junction. It receives the value of traffic density from RSU and based on that it assigns priority and calculates green phase time for each traffic edge.

Algorithm 1 depicts the process of zone wise traffic density calculation. After every *TLCtimer* expires, RSU notifies OBUs about its ID, location and zone details using *Density Request message*. All the vehicles within the range of RSU calculate their distance (*D*) from signalized traffic intersection using Haversine formula [34]. Based on the calculated distance (*D*) and length of each zone received in *Density Request message*, vehicle determines its zone and generates *Vehicle Response message* containing *VehID, EdgeId, ZoneId, VehType, NextNodeId* and *AvgSpeed*. Upon receiving *Vehicle Response message*, RSU restricts duplication by checking the existence of *VehID* in *VehList*. If *VehID* does not exist in *VehList* then *VehID* will be added in *VehList* and the value of *VehCount* for a particular edge and zone is incremented. The average speed determined by the vehicle is added to the vector *VehSpeed*. To determine traffic density on edge, RSU constructs the vehicle density vector (*VehDensity*) for each edge and zone.

Algorithm 2 depicts the process of priority weight calculation for each edge. Firstly, saturation density (*SD*) for each zone is calculated based on the value of zone length, vehicle length and inter-vehicle gap. To provide fair weightage to all the zones, value of multiplication factor (*MF*) is calculated based on saturation density and lane count. Multiplication factor for zone-3 is always 1. Finally, value of *EdgeWeight* for each edge is determined based on the zone wise value of multiplication factor and vehicle density. Vector *PriorityWeight* will be sorted based on the value of *EdgeWeight* and edges will be given green phase in descending order of *EdgeWeight*.

Algorithm 3 presents the way of calculating green phase time for each edge considering the presence of vehicles in different zones and traffic speed. Actual speed of the vehicle on a specific edge is dependent on the edge occupancy of that edge. Edge occupancy of an edge is the ratio of sum of vehicles travelling in any zone to sum of saturation density of the zone, for all the zones where vehicle exist. Considering this fact into account, to determine green phase time, edge occupancy is used along with zone distance and traffic speed. This inclusion ensures sufficient green time allocation to eligible vehicles for crossing the traffic intersection. Since we segregate eligible vehicles in three zones, there are three different scenarios possible. In first scenario, vehicles only exist in any one zone whereas in second scenario, vehicles exist in any two zones and finally in third scenario, vehicles exist in all the three zones. Proposed algorithm uses the value of *PriorityEdge* to identify that which scenario is applicable on a particular edge and based on that, value of other parameters will be determined.

## 5. PERFORMANCE EVALUATION

### A. Experimental Setup:

To evaluated the performance of proposed TLC mechanism along with other three, a simulation testbed is prepared using SUMO (Simulation of Urban MObility) [35] microscopic traffic simulator considering the traffic characteristics based on the free flow model [36]. Communication between vehicle and infrastructure is supported by Two-ray ground radio propagation model [37] configured in NS-2 [38] network simulator. Two different cases, one for single traffic intersection and other for the corridor considering a nine and half kilometer long road segment of Ahmedabad city with five signalized traffic intersections are assessed here. Each intersection has four approaches with total eight lanes in approaching and exiting directions. TLC module at each traffic intersection is implemented using Python program and TraCI [39] interface to control vehicular movement and traffic signal phases according to real-time traffic scenarios. Vehicle arrival rate follows the poison distribution [40]. To test the proposed approach for different traffic loads, vehicle density from 500 vehicles/hour to 6000 vehicles/hour is considered which move according to the manhattan mobility model [40][41]. Moreover, 10% heavy motor vehicles are taken into account along with light motor vehicles to make simulation more realistic to urban traffic scenario. Summary of simulation parameters is presented in Table III.

### B. Result Analysis:

Performance of the proposed TLC mechanism is compared with ETLSA [8], WALABI [11] and EVP-STC [13] considering average waiting time of travelling vehicles and average intersection throughput as performance parameters. Average waiting time is the average of waiting time of all the vehicles during their trip and average intersection throughput is the average of number of vehicles which have crossed intersections without any waiting.

#### 1) Effect of Traffic Density on Average Waiting Time for Single Traffic Intersection

Figure 4 demonstrates the performance of all the four TLC mechanisms considering average waiting time. It clearly exhibits that the performance of the proposed mechanism is improved by 37%, 59% and 62% with compared to ETLSA, EVP-STC and WALABI respectively for single traffic intersection. The main reason behind this improvement is the efficient design of proposed mechanism. In ETLSA, EVP-STC and WALABI a fixed length is defined for Ready Area (RA) and priority of each edge is decided based on traffic density in the RA of that edge whereas in

**Algorithm 1** Zone Wise Traffic Density Calculation

**Input:** $TLC_{timer}$
**Output:** $VehDensity\langle EdgeId, ZoneId, VehCount\rangle$
**Initialization:** $i \leftarrow 0, j \leftarrow 0, VehCount_{EdgeID}[] \leftarrow 0$

```
while 1 do
    if TLC_timer is expired then
        /*Re-Initialization of current phase*/
        purge_cache(VehList[])
        purge_cache(VehDensity⟨⟩)
        purge_cache(VehSpeed_EdgeId[])
        /*Density Request Message by RSU*/
        OBU ← ⟨RSUId, "DR", (LAT_RSU, Long_RSU), [Dist_Z1, Dist_Z2, Dist_Z3], Timestamp⟩
    end if
    /*Zone identification by OBU*/
    D ← 2 arcsin( sqrt( sin^2((Lat_RSU − Lat_Veh)/2) + cos lat_RSU * cos lat_veh * sin^2((Lat_RSU − Lat_Veh)/2) ) )
    if D ≤ Dist_Z1 then
        ZoneId ← 1
    else if D ≤ Dist_Z2 then
        ZoneId ← 2
    else if D ≤ Dist_Z3 then
        ZoneId ← 3
    end if
    /*Vehicle Reply Message by OBU*/
    RSU ← ⟨VehId, VehType, "VR", EdgeId, ZoneId, NextNodeId, AvgSpeed, Timestamp⟩
    /*RSU receives the reply message by OBU*/
    if VehId ∉ VehList[] then
        VehSpeed_EdgeId[i] ← AvgSpeed_VehId
        VehList[j] ← VehId
        if ZoneId = 1 then
            VehCount_EdgeId[Z1] ← VehCount_EdgeId[Z1] + 1
        else if ZoneId = 2 then
            VehCount_EdgeId[Z2] ← VehCount_EdgeId[Z2] + 1
        else
            VehCount_EdgeId[Z3] ← VehCount_EdgeId[Z3] + 1
        end if
        i ← i + 1
        j ← j + 1
    end if
    /*Constructing Traffic Density Vector*/
    while EdgeId ≤ 4 do
        while ZoneId ≤ 3 do
            VehDensity⟨EdgeId, ZoneId⟩ ← VehCount_EdgeId[ZoneId]
            ZoneId ← ZoneId + 1
        end while
        EdgeId ← EdgeId + 1
    end while
end while
```

$$D \leftarrow 2\arcsin\left(\sqrt{\sin^2\left(\frac{Lat_{RSU}-Lat_{Veh}}{2}\right) + \cos lat_{RSU} * \cos lat_{veh} * \sin^2\left(\frac{Lat_{RSU}-Lat_{Veh}}{2}\right)}\right)$$

**Algorithm 2** Priority Weight Calculation

**Input:** $Dist_{Z1}, Dist_{Z2}, Dist_{Z3}, AvgVehLength, VehDensity\langle EdgeId, ZoneId, VehCount\rangle$
**Output:** $PriorityWeight\langle EdgeID, EdgeWeight_{EdgeID}\rangle$
**Initialization:** $Gap \leftarrow 1, MF_{Z3} \leftarrow 1, LaneCnt \leftarrow 2, EdgeId \leftarrow 1, ZoneId \leftarrow 1$

```
/*Calculating Saturation Density (SD) for each Zone*/
while ZoneId ≤ 3 do
    SD_ZoneId ← Dist_ZoneId / (AvgVehLength + Gap)
    ZoneId ← ZoneId + 1
end while
/*Determine Multiplication Factor (MF) for each Zone*/
MF_Z2 ← SD_Z3 * LaneCnt + 1
MF_Z1 ← MF_Z2 * (SD_Z2 * LaneCnt + 1)
/*Calculating Priority Weight for each zone*/
while EdgeId ≤ 4 do
    EdgeWeight_EdgeId ← Σ_{ZoneId=1}^{3} VehDensity⟨EdgeId, ZoneId⟩ * MF_ZoneId
    PriorityWeight⟨EdgeId⟩ ← EdgeWeight_EdgeId
    EdgeId ← EdgeId + 1
end while
/*Sort vector PriorityWeight based on EdgeWeight*/
sort(PriorityWeight⟨EdgeId, EdgeWeight_EdgeID⟩)
```

**Algorithm 3** Calculate Green phase time

**Input:** $MF_{Z1}, MF_{Z2}, MF_{Z3}, Dist_{Z1}, Dist_{Z2}, Dist_{Z3}, SD_{Z1}, SD_{Z2}, SD_{Z3}, VehDensity\langle EdgeId, ZoneId, VehCount\rangle$, $PriorityWeight\langle EdgeId, EdgeWeight_{EdgeID}\rangle, VehSpeed_{EdgeId}[]$
**Output:** $GreenPhase\langle EdgeID, GreenTime_{EdgeID}\rangle$
**Initialization:** $MF_{Z3} \leftarrow 1$

```
while EdgeId ≤ 4 do
    EdgeOccupancy_EdgeId ← (Σ_{ZoneId=1}^{3} VehDensity⟨EdgeId, ZoneId⟩) / (Σ_{ZoneId=1}^{3} SD_ZoneId)
    if PriorityWeight_EdgeId ≥ MF_Z1 then
        /*Vehicles are only within Zone-1*/
        if PriorityWeight_EdgeId mod MF_Z1 = 0 then
            GreenPhase_EdgeId ← Dist_Z1 / median(VehSpeed_EdgeId[]) * EdgeOccupancy_EdgeId
        /*Vehicles are available within Zone-1 and Zone-2*/
        else if PriorityWeight_EdgeId mod MF_Z2 = 0 AND PriorityWeight_EdgeId > MF_Z1 then
            GreenPhase_EdgeId ← (Σ_{ZoneId=1}^{2} Dist_ZoneId) / median(VehSpeed_EdgeId[]) * EdgeOccupancy_EdgeId
        /*Vehicles are available in all the zones*/
        else if PriorityWeight_EdgeId mod MF_Z2 ≠ 0 AND PriorityWeight_EdgeId ≥ MF_Z1 + MF_Z1 + MF_Z1 then
            GreenPhase_EdgeId ← (Σ_{ZoneId=1}^{3} Dist_ZoneId) / median(VehSpeed_EdgeId[]) * EdgeOccupancy_EdgeId
        end if
    else
        /*Vehicles are only within Zone-2*/
        if PriorityWeight_EdgeId mod MF_Z2 = 0 then
            GreenPhase_EdgeId ← (Σ_{ZoneId=1}^{2} Dist_ZoneId) / median(VehSpeed_EdgeId[]) * EdgeOccupancy_EdgeId
        /*Vehicles are only within Zone-3*/
        else
            GreenPhase_EdgeId ← (Σ_{ZoneId=1}^{3} Dist_ZoneId) / median(VehSpeed_EdgeId[]) * EdgeOccupancy_EdgeId
        end if
    end if
    EdgeId ← EdgeId + 1
end while
```

TABLE III. SIMULATION PARAMETERS

| Parameter | Value(Single Intersection) | Value (Corridor) |
|---|---|---|
| Area of Simulation | 1900 m X 1900 m | 9500 m X 1900 m |
| No. of Traffic Intersection | 1 | 5 |
| Length of Road | 1900 m | 925 m - 2680 m |
| Trip Distance | 3800 m | 479 m - 9986 m |
| Traffic density | 500 veh/hr – 3000 veh/hr | 1000 veh/hr – 6000 veh/hr |
| Vehicle velocity | 5.5 m/s - 11.11 m/s | 5.5 m/s - 11.11 m/s |
| No. of lanes per Approach | 2 | 2 |
| Inter vehicle gap | 0.5 m – 1 m | 0.5 m – 1 m |
| Vehicle length | 4 m – 12 m | 4 m – 12 m |
| Traffic model | Free flow model | Free flow model |
| Mobility model | Manhattan mobility model | Manhattan mobility model |
| Wireless communication range | 300 m | 300 m |
| MAC Type | IEEE 802.11 p | IEEE 802.11 p |
| MAC delay | 20 ms | 20 ms |
| Message size | 10 kb – 20 kb | 10 kb – 20 kb |
| Transmission rate | 1 Mbps | 1 Mbps |
| Propagation model | Two ray ground | Two ray ground |

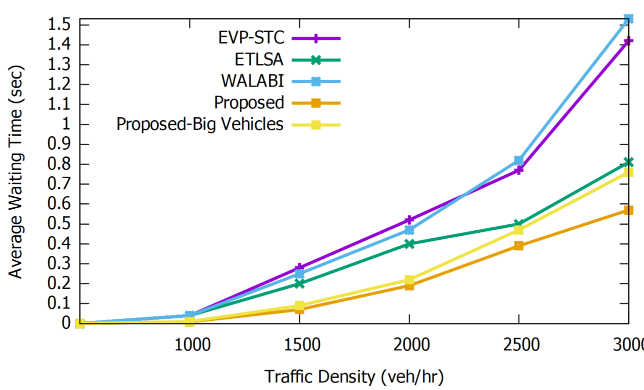


Figure 4. Traffic Density Vs Average Waiting Time for Single Traffic Intersection

the proposed mechanism, RA is divided in three zones and priority of each edge is calculated based on traffic density in each zone and multiplying factor. Near the zone from traffic intersection, higher the multiplying factor is. This ensures that vehicles near to traffic intersection get higher priority compare to vehicles those are far.

The green phase timing in EVP-STC and WALABI is calculated based on length of RA and average speed of the traffic; in ETLSA, the same is calculated based on the distance of last vehicle travelling in RA from traffic intersection and speed of the vehicle whereas in proposed mechanism, green phase time for each edge is calculated considering availability of vehicles in each zone, distance of latest zone in which vehicle exist from traffic intersection and average traffic speed. This proposed methodology for green phase time calculation reduces the waiting time of travelling vehicles mainly for low and moderate traffic scenarios because for low and moderate traffic scenarios, traffic density in RA is also low or moderate but length of RA (for EVP-STC and WALABI) or distance of last vehicle from traffic intersection (for ETLSA) is more so more green phase time is allocated and hence vehicles on other edges have to wait more whereas in proposed mechanism, if no vehicle is exist in zone-3 then its length will not be counted in RA which allocates less green phase time which in-turn reduces the waiting time of other vehicles waiting at traffic intersection.

Figure 4 also shows that when traffic density approaches towards pick, sudden rise is noticed in average waiting time for EVP-STC and WALABI whereas for proposed mechanism and ETLSA, increase is mostly consistence. This difference is because of the density dispersion model used by different TLC mechanisms. In EVP-STC and WALABI, entire traffic is distributed in four traffic flows and more dense traffic flow gets green phase first whereas in proposed mechanism and ETLSA, the entire traffic is distributed in eight different traffic flows and two most dense non-conflicting traffic flows get green phase first in parallel.

To make more realistic urban traffic scenario, heavy motor vehicles are also included in traffic and the performance of proposed mechanism with heavy motor vehicles is also presented in Figure 4. From the figure, it can be observed that no noticeable increased in the average waiting time for low and moderate density scenarios but for high density scenario, around 20% increase in average waiting time is seen. This is because of the fact that, for low and moderate traffic density, fast moving vehicles can get the space to overtake heavy motor vehicles and thus can cross the traffic intersection within green phase whereas in high traffic density scenarios since the road is mostly occupied, fast moving vehicles need to follow heavy motor vehicles.

*2) Effect of Traffic Density on Average Waiting Time for Corridor*

The performance comparison for all the above discussed TLC mechanisms considering the 9.5 km long corridor is presented in Figure 5. It is clearly visible from the Figure 5 that the average waiting time for the proposed mechanism is reduced by 68%, 70% and 79% compared to the performance of WALABI, EVP-STC and ETLSA respectively for low and moderate traffic density whereas for high traffic density scenario, it is 85%, 84% and 74%

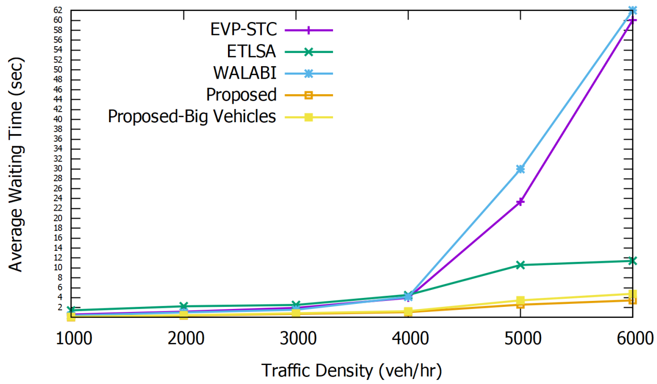


Figure 5. Traffic Density Vs Average Waiting Time for Corridor

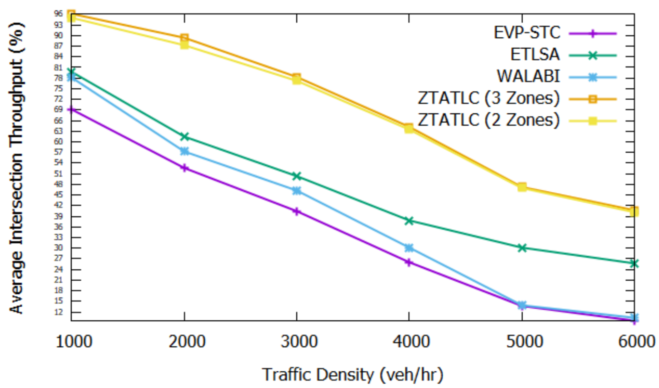


Figure 6. Traffic Density Vs Average Intersection throughput for Corridor

respectively. For proposed mechanism with heavy motor vehicles, the average waiting time is increased by 16% but still it outperforms WALABI, EVP-STC and ETLSA. This improvement in both the cases is because of the aforementioned reason stated in the case of single traffic intersection.

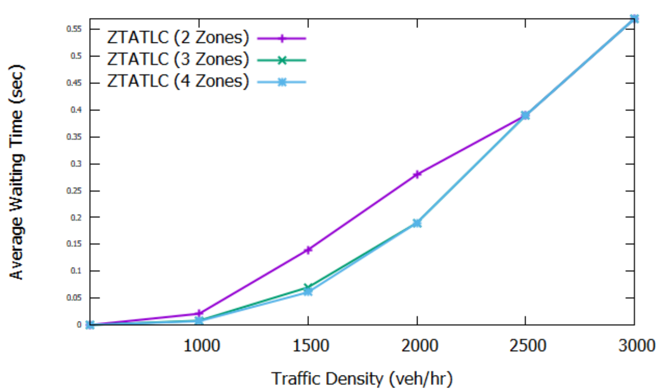


Figure 7. Traffic Density on Average Waiting Time considering different values of Number of Zones for Single Traffic Intersection

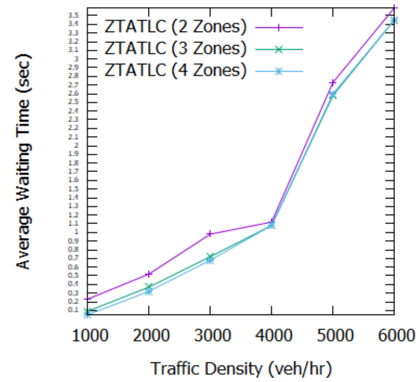


Figure 8. Traffic Density on Average Waiting Time considering different values of Number of Zones for Corridor

*3) Effect of Traffic Density on Average Intersection Throughput*

Figure 6 represents the performance of all the TLC mechanisms considering average intersection throughput and it is clearly visible that the proposed mechanism outperforms the other mechanisms. The main reason behind this improvement is the zone based design of the proposed mechanism. Due to this design, optimal green phase time is allocated to all the edges and hence vehicles can cross the traffic intersection without any hindrance.

*4) Effect of Traffic Density on Average Waiting Time considering different values of Number of Zones*

For the proposed mechanism, the critical parameter is to decide an adequate number of zones. If number of zone is less than the optimal value then it will hamper the performance of the proposed mechanism and if it is greater than the optimal value then computational resources will be wasted due to requirement of more processing capabilities. Figure 7 and Figure 8 show the effect of number of zones considered on average waiting time. Figures clearly state that, for low and moderate traffic scenarios, the average waiting time is improved by 12% and 9% for single traffic intersection and entire corridor respectively considering three and four zones with compared to two zones whereas for high density scenario, minor difference is observed for all the three cases. When two zones are considered, the length of each zone is increased and green phase time is also increased since it is calculated based on distance of the zone from traffic intersection and traffic speed. So for low and moderate traffic scenarios, even though the traffic is less, more green time will be allocated which decreases green time utilization and vehicles on other edges need to wait for longer amount of time. The same case is not exactly applicable for high traffic density due to existence of more vehicles in zones which in-turn increases green time utilization and overall waiting time is not much affected.

## 6. CONCLUSION

A VANET based novel TLC mechanism for minimizing average waiting time of vehicles is proposed in the paper.

In the proposed mechanism, the ready or green area on each edge is divided in three zones and each zone has its own priority weight (multiplying factor). The priority weight is inversely proportional to distance from traffic intersection i.e. higher the distance, lower the multiplication factor. Priority weight for each edge is calculated based on traffic density in each zone and zone's multiplication factor. The green phase is allocated in descending order of the value of priority weight. The green phase time assigned to each edge is determined considering traffic speed and the maximum of distance of zones from traffic intersection for all the zones where vehicle exist.

In order to evaluate the performance of the proposed TLC mechanism, a 9.5 km long road segment from Ahmedabad city is prepared using SUMO in which all the possible traffic scenarios are incorporated. Python along with TraCI is used to control the movement of vehicles and schedule of traffic light. NS-2 network simulator is also used to facilitate vehicle to infrastructure (V2I) communication. The result shows considerable reduction in average waiting time for vehicles travelling on the road for both single traffic intersection and the whole corridor. One can also infer that the optimal performance can be achieved by dividing ready area into three zones.

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