IMAC- Intersection MAC Protocol optimized for Lane Switching at Traffic intersection

Hitender Vats* and Ranjeet Singh Tomar
ITM University Gwalior, India
HVATS@HOTMAIL.com
RanjitTomar@itmuniversity.ac.in

Abstract. The intersection of traffic flow at Red-light Crossing is the only hurdle in otherwise smooth and speed drive in Modern Cities. The co-operative driving under the preview of ITMS (Intelligent Traffic Management System) utilizing VANET is a promising solution of long traffic jam on Red-light crossing. This paper proposes a new traffic control protocol **CACA** (Collision Avoidance Crossing intersection Algorithm) which will not only enhances the throughput in term of vehicles passing through by a factor of 1.3 but also decreases the Trip delay considerably. Unlike work done till date on co-operative driving utilising VANET which focused on dividing the area into smaller cells, we have designed this protocol focused on using Lane as a building block. Also we are proposing a newly designed **I-MAC** (Intersection MAC protocol) which is specifically designed to maximize the benefit of CACA. Simulation result shows that combination of our designed protocols will enhance the safety by avoiding collision of vehicles. I-MAC not only reduces data packet drop significantly but also provides real time reliability of Safety messages. It also improves effective Bandwidth utilization having variable slot duration to respond to varying traffic density at intersection.

Keywords: VANET; Adhoc Network; Cooperative driving ; Multi Agent System ; ITMS ; MAC Protocol

1 INTRODUCTION

To improve upon legacy system of Fixed Timing Redlight based traffic control system, Adaptive Red Light control system was proposed wherein the Green light time and Light Phase sequence both are changed for better optimisation. However, problem is that all this is a ‘Passive’ method. Now we have intelligent vehicles, which has on-board computational system along with smart sensors. This Intelligent vehicle ‘continuously’ broadcast their position, intended future movement alongwith other relevant desired parameters. Intelligent Traffic Management System (ITMS) is a new approach in traffic control system, removing the requirement of vehicles to stop at Redlight intersections thereby increasing intersection’s capacity. The use of V2V (Vehicle to Vehicle) communication decreases crossing time for each vehicle to cross the intersection. Its successfully proven that the Cooperative Adaptive Cruise Control (CACC) easily facilitate smooth traffic with shorter inter-vehicle distance. This concept of compactly placed cars in platoon is extended to intersection control system, wherein colliding traffic flow can pass the Intersection with minimal inter-vehicle distance without need of a Redlight traffic signal, which not only reduces the stop time considerably but also enhances intersection capacity.

We know that the Drivers among themselves resolve the traffic conflict in manually driven vehicles, at intersection region by virtue of their experience. It is done by securing the optimum spacing between vehicles, in order to cross the intersection smoothly without crash. A better control strategy using Lane Change with a novel algorithm specifically designed for Crossing Intersection has been proposed in this paper. Achieving the increased throughput is the aim of this optimisation. As both Inter-Lane and Intra-Lane traffic control are required for traffic at Entry of Intersection, Lane change decisions and speed controls needs to be coordinated and optimized to achieve enhanced traffic control performance.

The remaining of the paper is in following manner. Section 2 discusses related work to both Automatic Crossing Intersection control algorithms as well as MAC communication protocols. Section 3 introduces our designed CACA (Collision Avoidance in Crossing intersection Algorithm) protocol. Section 4 describes IMAC (Intersection MAC) protocol. Section 5 deals with Experimental setup to evaluate our newly proposed protocol in Simulated environment, while conclusion is discussed in section 6.

2. Intersection Management using VANET

A Crossing or any intersection can be modelled as a special case of Lane merging and Lane changing. **Umer Khan et al** [1] examined intelligent lane change models based on the cooperation among connected (by wireless communication) vehicles for traffic management and travel time optimization. Initial work on intersection management without Red-light was proposed by **Raravi et al**.[2] by mean of formulating an optimization problem . **Uno et al** [3] modelled the merge control application with virtual vehicles in ITMS.

A new Infrastructure Signalling Unit based Intersection Control Management / Philosophy has been introduced wherein profiles (velocity, acceleration and distance) of vehicles, which are inside the *Area of interest, will* be tracked by ISU. This has been amplified with help of Crossing Intersection are drawing as depicted in Figure 1. **Dresner and Stone** [4] presented autonomous intersection management (AIM) which became a milestone for alternative systems to the traditional Redlight based traffic signal control system.

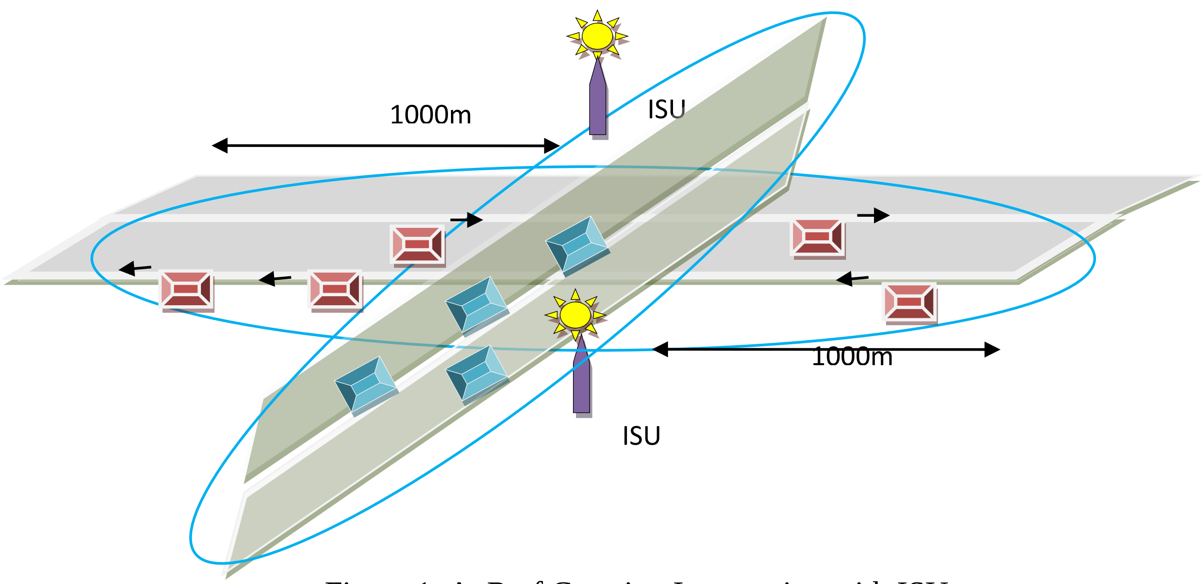

Figure 1. AoR of Crossing Intersection with ISU

J Lee & B Park[5] has proposed CVIC (Cooperative Vehicle Intersection Control) algorithm to alleviate the trajectory overlap on crossing intersection. VICS vehicle-intersection coordination scheme (VICS) was designed by **Kamal et al[6]** with risk function indicating portion of the intersection by quantifying the risk of a collision of a pair of vehicles.
Matteo Vasirani et al [7] proposed A Market inspired Approach wherein the problem with First Come First Serve policies was substituted by auction system. Here reservations are made as the process of assigning resources to vehicle agents as per bid cost. **Hesham Rakha et al** [8] proposed CTR algorithm . In this case, the trajectories of vehicles A and B are predicted to be intersected (i.e., potential collision) at time tc, indicating insufficient gap.If the manipulation of vehicles based on the projected vehicular trajectories is feasible (i.e., a Cooperative Vehicle Infrastructure System), the insufficient gap might be adjusted to make a sufficient gap.

Xi Zou and David Levionson [9] proposed Group competition of vehicles from different direction. While **Remi tachet et al** [10] has studied Slot-based Intersection Control which doubles the capacity. They proposed **Fair & Batch** and they found that service rate reaches its optimal capacity as the maximal number of vehicles in platoon increases.

Reza Azimi et al [11] proposed CDAI which ran on all vehicle & using TCL through BSM(Basic Safety Message). It additionally use three type of safety message namely : **ENTER , CROSS, Exit .**CROSS message will keep on updating TCL using GPS while calculating its present coordinates, Speed & map database. Enter & EXIT message are broadcasting when vehicle distance from Crossing Intersection is Less or more respectively than a critical distance D[critical] . While **Q. Lu and K.-D. Kim [12],** presented Discrete-Time Occupancies Trajectory based system for ITMS.

2.1 MAC PROTOCOL FOR VANET COMMUNICATION

Maheshwari et al [13] presented the parameter less broadcast in static to highly mobile(PBSM) adhoc networks protocol and they also studied a multi-channel token ring MAC protocol (MCTRP) for inter-vehicle communication. **Sommer et al**[14] presented a new message dissemination protocol, Adaptive Traffic Beacon (ATB), which is fully distributed and uses adaptive beaconing based on message utility; and the channel quality. **Dikaiakos et al** [15] proposed Location aware services over VANET using RSU-free car to car communication. They investigate the problem of developing services that can provide car drivers with time-sensitive information about traffic conditions and roadside facilities. They introduced the Vehicular Information Transfer Protocol (VITP), a location-aware, application-layer, communication protocol designed to support a distributed service infrastructure over VANET.

To obviate the problem of Faulty nodes, Pathak **et al** [16] propose to secure location aware services over VANET with our geographical secure path routing protocol (GSPR). Geographic locations of anonymous nodes are authenticated in order to provide location authentication and location privacy simultaneously. Their protocol also authenticates the routing paths taken by individual messages. **Kato et al** [17] stresses that the inter-vehicle communications for the vehicle control should not have any delay. Since the occasional data loss can be compensated by estimation and prediction with the Kalman filtering technique, the protocol must be designed with the assumption that the occasional data loss can be allowed and the continuous data loss cannot be allowed. **Noh et al** [18] proposed an automated system with respect to situation assessment and behavior decision for cooperative driving between a driver and the system.

More recently **Nguyen et al** [19] proposed a Hybrid Multichannel MAC protocol to increase throughput. It was a TDMA and CSMA mixes sytem. High throughput is achieved by eliminating unnecessary control overhead resulting in faster timeslot acquisition. **Wang et al** [20] had already proposed Multichannel MAC scheme with Channel Coordination . They proposed variable control channel interval to provide reduced transmission delay. Then **Cao et al** [21] presented SCMAC which was Scalable and Cooperative MAC protocol wherein scalability was achieved by proactive slot reservation. The slot access method ensured enough idle slots to be joined by more new nodes. R. S. Tomar and S. Verma[22] proposed a RSU centric channel allocation in vehicular ad-hoc networks. **Steinmetz et al** [23] had presented collision Aware MAC scheme. There strategy is based on self-triggered approach which bridges gap between control, sensing and communication . **Sanguesa et al** [24] has nicely summed various Hybrid Cooperative MAC scheme in their survey paper. They have provided a fair comparative analysis by evaluating them under the same environmental conditions, focusing on the same metrics, and using the same simulation platform.

In this paper a new MAC protocol has been designed which will suit our newly designed Intersection controlling CACA algorithm maximising its efficiency. This protocol will have many messages with different Prioritisation Scheme. Effort has been made to study effect of no. of user on the performance of MAC protocol

3 Lane Change in Crossing intersection Algorithm

3.1 Collision avoidance in Crossing intersection Algorithm(CACA) We have designed a new Algorithm whose basis is the fact that Lane and Lane change can become basis of any traffic scenario modelling. We have modelled a 2 lane and also a 3 lane traffic road system with inner, middle and out lane, which jointly makes a ‘Road Segment’. For analysis purpose we use a Right hand driving. Unlike earlier designed protocol in co-operative driving utilising VANET which focused on dividing the area into smaller cells, we have designed this protocol focused on using Lane as a building block. We aim to examine the possibility of Lane change in Intersection area which is assumed to be prohibited in present time driver centred manual traffic management system.

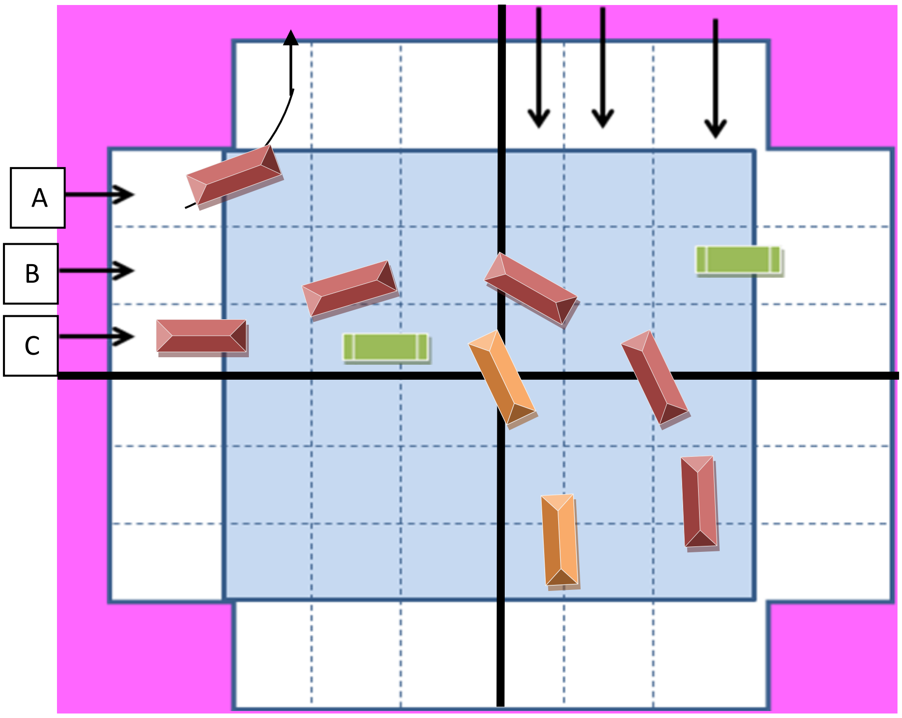

Figure 2. Overtaking in Intersection Area using CAIA

In our designed CAIA all vehicle entering in AoR(Area of Responsibility) of ISU have to be in correct lane. Refer Figure 2, it depicts the crossing intersection with 3 Lane traffic on each entering side. For any vehicles entering from East side, it can go Straight or turn Left or Right e.g A,B and C in this case. Vehicles wanting to Turn Right vehicle should be in Outer Lane. Similarly Vehicles intending to turn Left should be in inner most lane. This transformation of vehicle in correct lane should happen 200m before intersection area to avoid collision or slowing of traffic. This is fructified by Mandatory LC (Lane Change) message set. For vehicle 'B' willing to take right turn will explore if there is possibility of Lane change if the vehicle ahead is slow e.g. vehicle 'A' in our case.

This vehicle will be allowed to change Lane subject to condition that Safety as well Benefit criteria are met. This is fructified with help of **OptionalLC** (Elective Lane Change) message set . Algorithm running on ISU will decide to allow overtaking only if it founds any benefit in overall efficiency of intersection traffic flow. It can ask vehicle to accelerate or de-accelerate according to situation whichever is more beneficial keeping safety criteria in mind. Also if by chance at any time the ISU decides or the driver of vehicle feels that it cannot pull off this Over Taking, the **FallBack** (Abort Lane Change) Message set is utilised. This is highest priority message which has to be delivered fail safe and in real time. After completing the successful overtaking, the vehicle gives **Exit** message indicating that it has finished utilising the Intersection service and continues on its intended/ desired lane. Accordingly the CAIA protocol will delete it from its list of vehicle to be managed in its AoR.

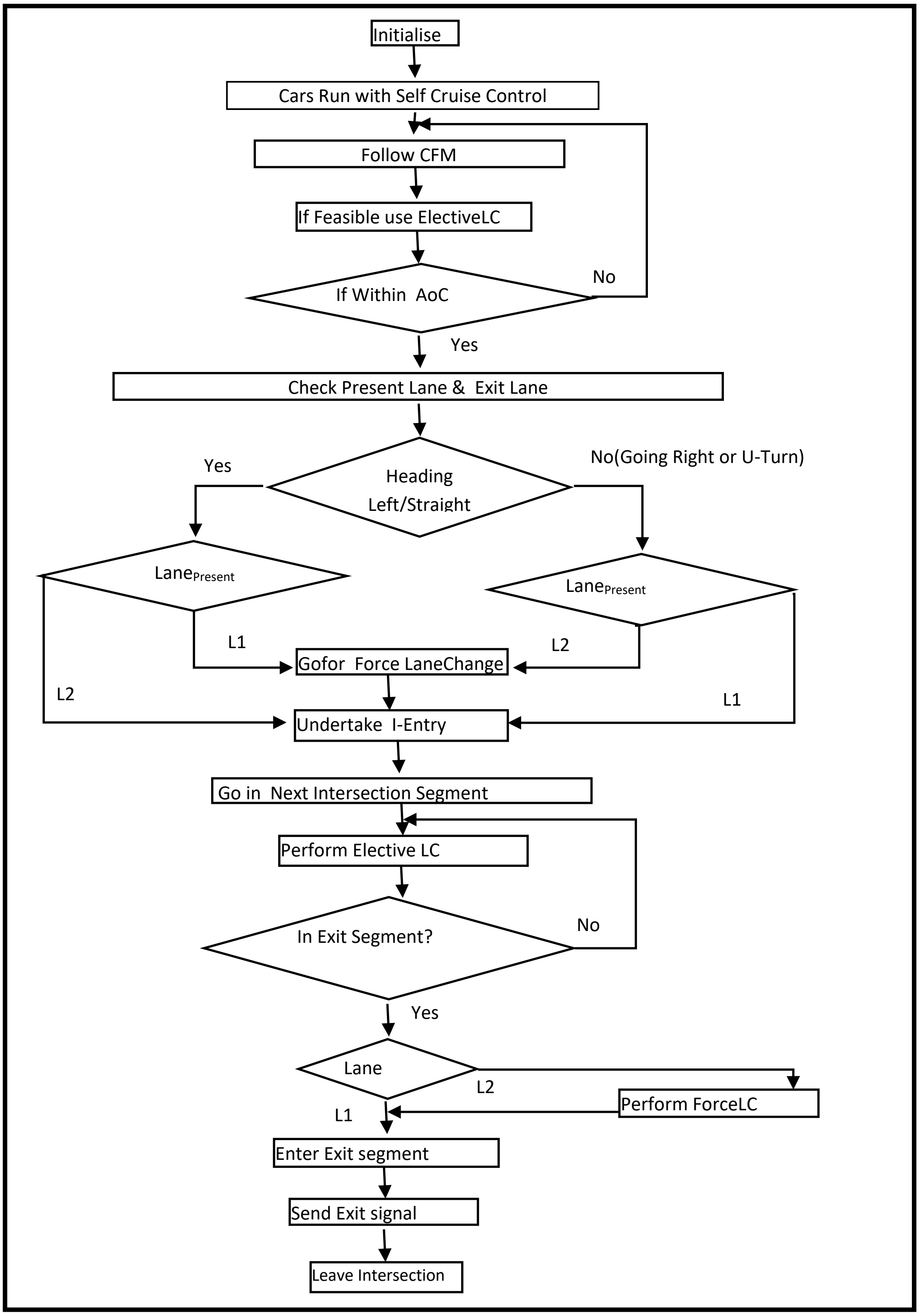

Figure 3. Flowchart depicting CACA running at Intersection ISU

4. Design of IMAC: Intersection MAC Protocol Customized for Lane Change

The job of intelligent crossing/Intersection Management system cannot be effectively implemented without the important role of Vehicle Ad-hoc Network, which provided communication link to connect these intelligent vehicles acting as multi agents. For Safety message, it is a necessary that these messages are received in near real time. As seen, in our case, there are three kind of message safety related, Lane Change related and less important informative messages. All the safety message are given highest priority while all messages which give some kind of information are given least priority since they are delay tolerant in nature.

MAC PROTOCOL OPERATION

The ISU controlled frequency allocation in this protocol by avoiding contention based reservation of slots, makes efficient use of frequency spectrum. In the proposed protocol, ISU broadcasts the beacon message through Assignment channel with its own Intersection controller ID, Lat Long of its geographical location. Each car will continuously monitor this channel as it also contain security messages. As the vehicle enter into ISU control range 1500 meters in our case, it sends a association request ISU sends a confirmation message taking over control of vehicle till it is out of its control range on its outbound lane. Depending on vehicles geographical location, ISU assigns Road Band or Intersection band for communication. When vehicle has a message to transmit Depending up on its type it send request to ISU for channel assignment and wait for its response. ISU will maintain three register viz. Safety, Lane Change or Informative and will allocate channel on same priority. For addition Safety channel will also be allocated on Assignment Band if it is a request for Safety type of message. Message list of Informative Type will get allocation only when higher priority type of message list is empty.

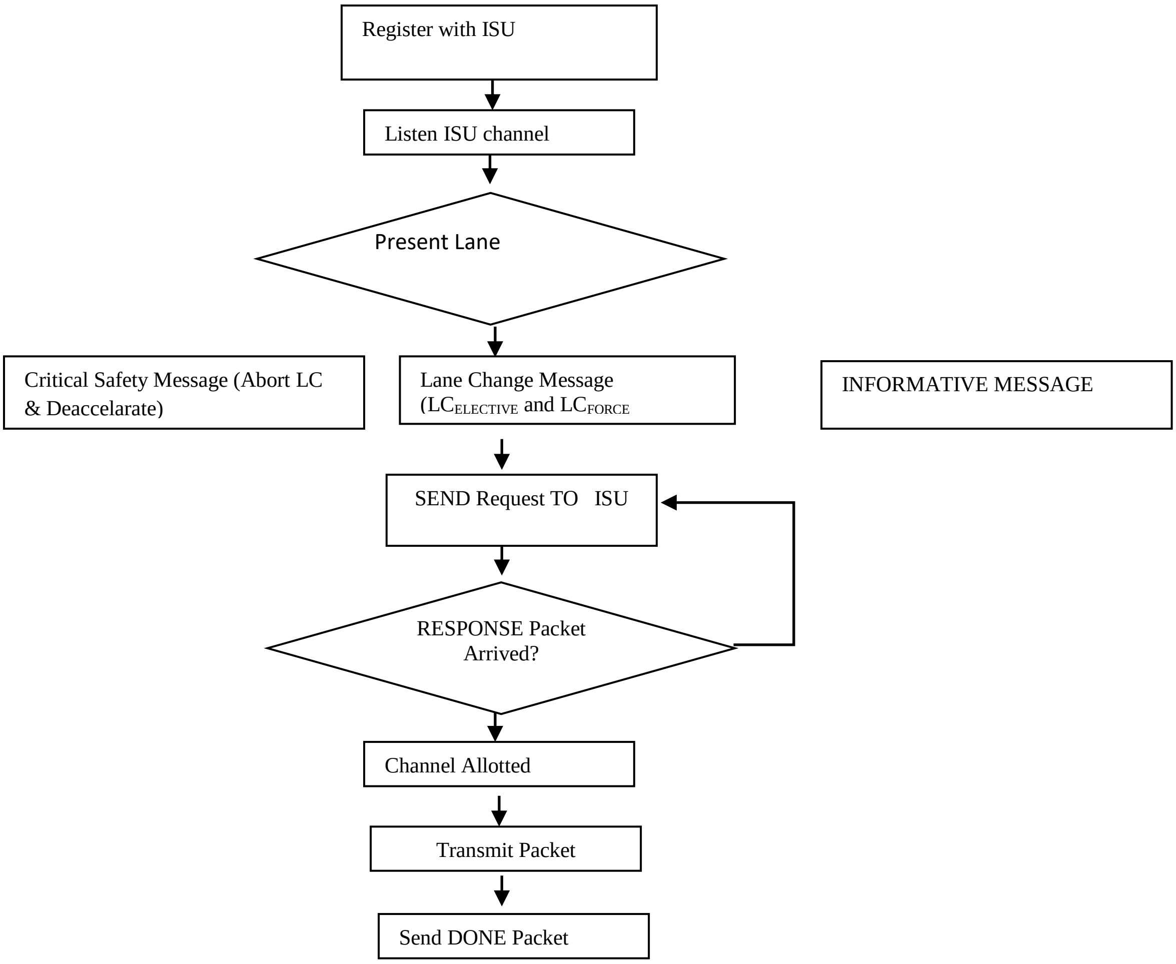

Fig. 4. IMAC Operation at Vehicle Agents

<u>Algorithm for Intersection specific Channel Access for VANET</u>

Step 1*: ISU broadcasts the beacon message its ID through Assignment channel*
Step 2*: Vehicle sends a association request*
Step 3*: ISU sends a confirmation message.*
Step 4*: ISU assigns Road Band or Intersection band.*
Step 5*: Vehicle request channel assignment to ISU and wait for its response.*
Step 6*: ISU maintain three register viz. Safety, Lane Change or Informative and allocate channel on same priority.*
Step 7*: Channel also allocated on Assignment Band for Safety type of message.*
Step 8*: Informative Type data get allocation after Safety message list is empty*
Step 9*: Car will send transmission complete packet to ISU.*

5 MODELING & SIMULATOR

5.1 PythonSim

This modular concept of Lane can be best simulated by use of Object Oriented Programming Software concept. We have utilised Python language for Simulation since it is widely used and is also a Open source OOPS(Object Oriented Programming Software) language.

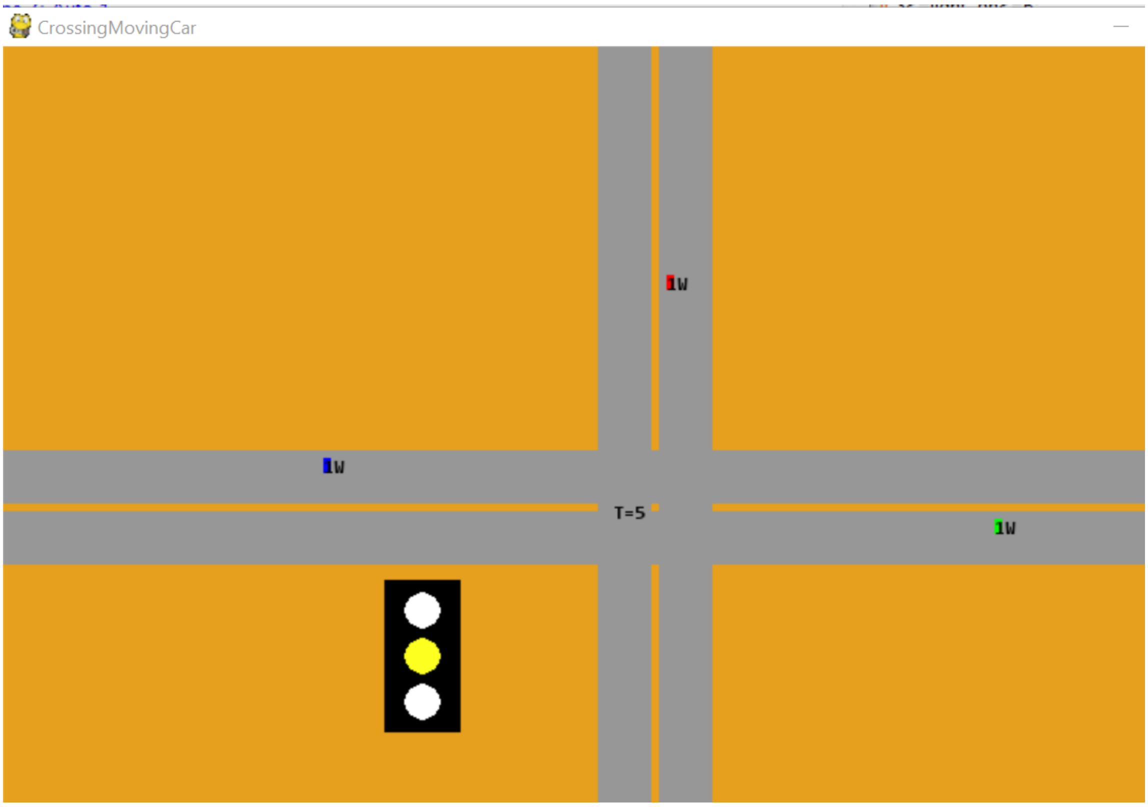

Figure 5 : Simulator Snap Shot

5.2 Experimental Setup for PythonSim

The main agent, 'ISU controller' is the one which coordinates with all other car in its Area of Responsibility. The inter-vehicle communication was restricted to cruise control in Lanes before entering the intersection and after leaving it only. The vehicles were added into Simulated system having randomised parameters like velocity, traffic route and different braking coefficient. To perform comparative study certain assumptions are taken like (a) Each car is of same size. (b)We neglect driver behaviour. (c) No skidding and slowing on Turns. (d) Cars immediately follow instructions passed by ISU without any delay.

We have designed a Test setup consisting of a 200Mtrs. radius Intersection having Two Lane traffic with 4 segments each at right angle with each other. Each segment is 2 K.M. lengthwise. Only 4 vehicle injected randomly in each segment per lane. The First car goes Straight whereas second car takes U-Turn. The third vehicle takes Leftside Turn & Fourth one will take Right turn. This way we there will be total of different 32 possible car Routes which can be simulated for evaluation of protocol.

Since ISU can afford to have unlimited power and computational power , it was entrusted the job of centralised control. Each ISU will have Eight highly directional antenna, each looking in direction as shown in Figure 8 .Four will look in East, North, West and South inbound as well as outgoing traffic while rest of four antenna will be catering for quadrant of intersection section . Cars were added to test scenario with random variable of velocity of 30 kmph and 60 kmph. There route viz entry lane and exit lane were also randomised for better analysis.

For simulation of communication protocol following parameter were used:-

Number of vehicle	16,32,64 and 128
Data rate	2Mbps
Packet	Universal Datagram Protocol
Traffic	Constt. Bit Rate Type
Size of Packet	Variable(20,50,100 bytes)
Generation rate of Packet	15 packet /second for ISU
Tx range of ISU	1500 meter
Tx range of Cars	500
Car Speed	30 and 60 km/h
Simulation Time	5 min
Antenna Type	8 Antennae Highly Directional Type

6 RESULT & ANALYSIS

The Figure 6 shows the graph of variation of average queue length with variation in vehicle density. It can be seen from the graph that average queue length is much small across all vehicle density than in normal case of Red light with 30 Sec timing. The ElectiveLC has further shorter queue length which is in line with our hypothesis that CARA with ElectiveLC will increase the throughput.

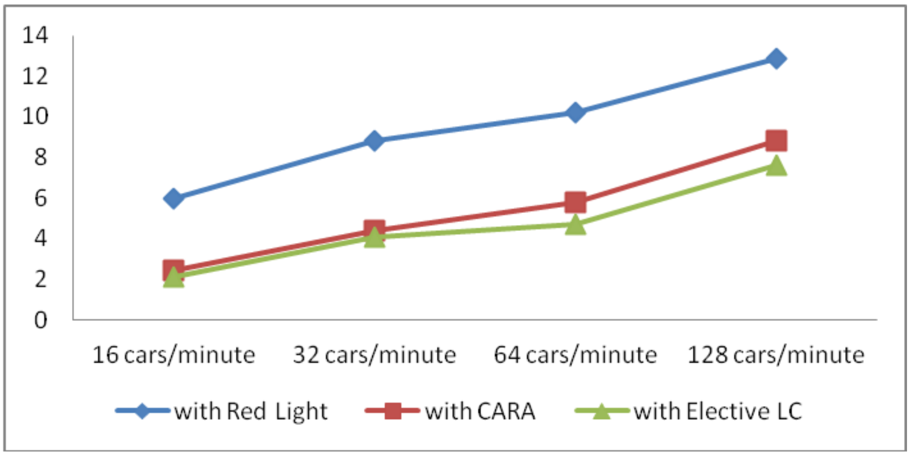

Fig. 6. Vehicle in Queue in 2 & 3 Lane System Vs Vehicle Density

The Figure 7 shows the graph of Packets reception ratio with respect to number of vehicles. Since we have considered four vehicle originating in four lane each, therefore the test scenario has vehicle density in multiple of 16 i.e. 16, 32, 64 and 128. As it is quite evident that packet reception ratio decrease with increase in vehicle density. This is in line with our hypothesis that the proposed MAC protocol will help in more efficient utilisation of available spectrum. Also the vehicles speed were increased from 30 Km/Hr to 60 Km/Hr which resulted in considerable drop in packet reception ratio.

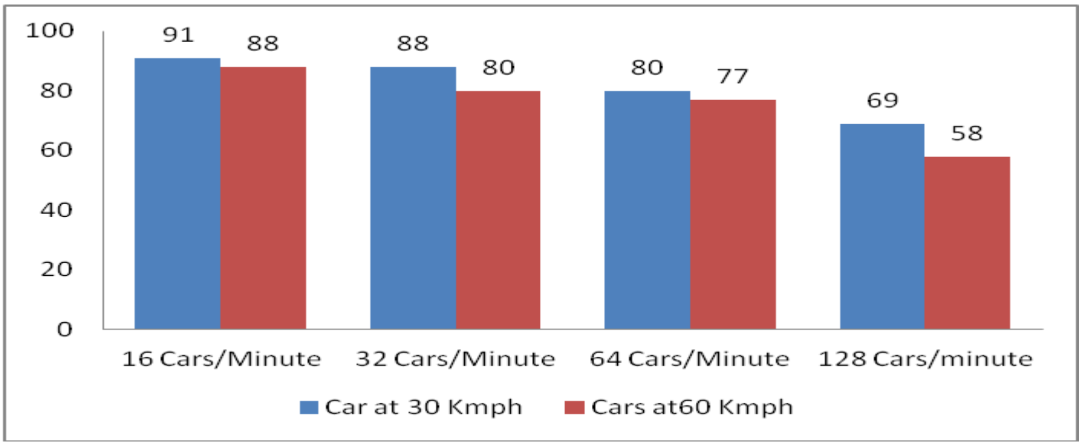

Figure 7. Packet reception ratio with change in Vehicle Density

7. <u>CONCLUSION</u>

The time consumed to pass the Intersection, by the vehicles, has to be reduced for increasing the intersection's Throughput. We had proposed to allow Lane change in intersection area without compromising the safety. Also Merging action of traffic after intersection area has been smoothly implemented. Conditions were derived and evaluated where benefit of Lane change overtakes the risk in safety. What CAIA control algorithm ensured was that no vehicle should come to total halt. It takes more time to attain a specific optimal speed from 0 than from a min speed V_{min}. This would increase the capacity as well average speed of vehicles in crossing/intersection. Also proposed algorithm will increase passenger comfort and Safety. Maximum algorithm use 'passive' mechanism of 'deceleration' while we would calculate the best mix of both 'active' mechanism of acceleration and deceleration.

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