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RMAC:
Customised MAC Protocol for Roundabout Management Using VANET for Coperative Driving

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ABSTRACT

One knows that smart transport is also an integrated part of healthcare technologies. To minimize the pollution for benefiting the healthcare, the traffic throughput on roundabout intersection has to be increased which will reduce wasted time and will also enhance passenger comfort. This paper presents a new approach by use of cooperative vehicular control utilizing VANET without compromising the safety of vehicles. This intersection side unit (ISU)-based system use lane change mechanism. The modular use of lane with lane change in newly designed protocol CARA (collision avoidance at roundabout algorithm) will greatly enhance the capacity utilization of roundabout. A new simulator 'RoundSim' was also developed exclusively for simulation in roundabout. A new MAC protocol RMAC (roundabout MAC) is also designed which will suit the roundabout management utilizing lane change to minimize sudden jerk to passengers, thus enhancing healthcare of people. This RMAC utilizes message set with different prioritization scheme which results in better utilization of allotted frequency spectrum.

KEYWORDS

Cooperative Driving, ITMS, ITS, MAC Protocol, Multi-Agent System, VANET

INTRODUCTION

The major problem faced by city planner of Developing country like India is its population which require mobility solution. With its ever increasing population and vehicle added to already hard-pressed road network, new technology for increasing the throughput of traffic in an unavoidable necessity. Intelligent Traffic Management System (ITMS) is a new technology which offers a practical and improvising solution. It has been successfully proved that the Cooperative Adaptive Cruise Control (CACC) can easily drive vehicles with shorter inter-vehicle distance by forming platoons to improve traffic-flow capacity. This concept of compactly placed cars in CACC can be extended to offer a new intersection control system, in which nearly colliding traffic flow from different directions can cross the Intersection with minimal gaps without need of a traffic signal thereby eliminating stop time and increasing the intersection capacity. Even though in some developed countries we have got Adaptive Red Light control system wherein the Green light timing period and Light Phase sequence both are change the for better optimisation. The problem is that all these method are 'Passive' method

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of finding the queue/no. of vehicle at Red-light. Now a new technology is evolving which makes the vehicle Intelligent. These Intelligent vehicles has got sensor on-board and they ‘actively’ broadcast their position, intended future movement on road and other relevant parameters.

To achieve ITMS importance of message transmission is upmost criticality. The messages have to be transmitted without delay. The main goal of the different dissemination strategies available till now is to reduce the message delivery latency of such information while ensuring the correct reception of warning messages in the vehicle’s neighbourhood as soon as a dangerous situation occurs. Despite the fact that several dissemination schemes have been proposed so far, their evaluation has been done under different conditions, using different simulators, making it difficult to determine the optimal dissemination scheme for each particular scenario.

In this paper a new MAC protocol has been designed which will suit our newly designed Roundabout controlling CARA algorithm maximising its efficiency. This protocol RMAC 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.

BACKGROUND

Roundabout Traffic Control Management System

The pioneering work in field of smoothning traffic flow was done by Yang and Li (2003) proposing of traffic control at Roundabout utilising signal with variable signal timing. Then G Tan, and Wang et al. (2011) further put forward the idea of Optimal Number of Vehicles in Roundabout (ONVR), calculated and optimised it. J Zhang et al (2012) used Artificial Intelligence with Fuzzy Logic wherein outer layer selected most urgent phase subset and while inner layer calculated current phase’s extension time of Redlight signalling controller. Reza Azimi et al. (2013) proposed CDAR (Collision Detection Algorithm for Roundabout) algorithm. Their algorithm checked whether there is any possibility of any collision of vehicles trajectories. They divided the entire intersection area in small cells for purpose of checking impending vehicles future location.

L C Bento (2012) implimented an ITMS in Time-Space region with Reservation Algorithm. They proposed layers of space in 3-Dimensions each representing time instance ‘ t ’. X Sun et al (2016) presented a comprehensive comparison of Capacity of different kind of traffic intersection including Intersection. More recently J Wu et al (2014) has emphasised on control mechanisms which can balance between safety and efficiency issues. They have proposed a sequence-based system for CIM (Cooperative Intersection Management). Coi et al (2018) has given emphasis on Reservation Based Cooperative traffic management of Multi-Lane roads with different traffic mixes. Altogether new approach was tried by Vasirani(2018) and Q Lu (2016). Finally Lei Chen (2016) has summed up various types of Cooperative intersection Management System in their survey paper. He has considered both signalised and non-signalised intersection which included four-way intersection with straight traffic, roundabout as well as four-way intersection with left, right turn along with straight traffic.

Mac Protocol for Vanet Communication

Maheshwari et al (2015) presented survey of broadcast in vehicular networks. They developed the Acknowledged Broadcast from Static to highly Mobile (ABSM) protocol, a fully distributed adaptive algorithm suitable for VANETs with all mobility scenarios. The parameter less broadcast in static to highly mobile(PBSM) adhoc networks protocol. They also studied a multi-channel token ring MAC protocol (MCTRP) for inter-vehicle communications (IVC). Through adaptive ring coordination and channel scheduling, vehicles are autonomously organized into multiple rings operating on different service channels. Based on the multi-channel ring structure, emergency messages can be disseminated with a low delay.

Sommer et al (2011) 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. It is shown that adaptive beaconing leads to a much broader dissemination of messages (in terms of penetration rate) than flooding-based approaches, albeit at a slower rate. Adaptive beaconing thus seems to be much more suitable for Traffic Info System than flooding-based protocols. Dikaiakos et al (2007) 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 obviates the problem of Faulty nodes, Pathak et al (2008) 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. (2002) 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 (2015) proposed an automated system with respect to situation assessment and behaviour decision for cooperative driving between a driver and the system. The proposed system includes three main parts: (1) high-level data fusion to produce a better understanding of the observed situation, (2) distributed reasoning based situation assessment to evaluate the current situation in the safety aspect and to recommend actions, and (3) behaviour decision to determine collision free and goal-directed manoeuvres for vehicle/driver cooperative and highly automated driving in highway environments.

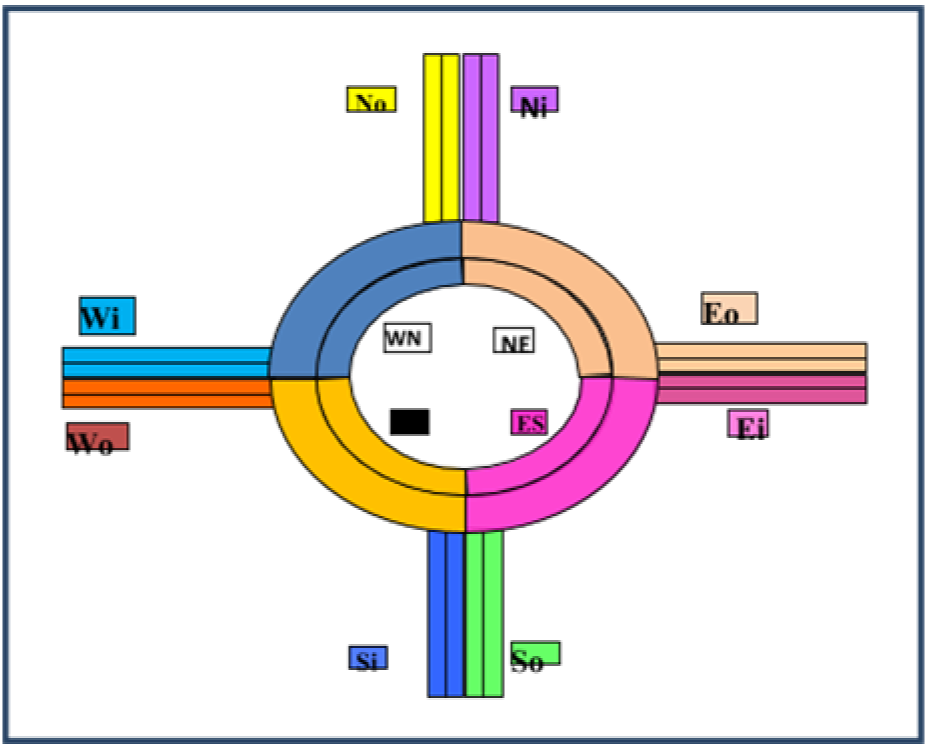
More recently Nguyen et al (2016) proposed a Hybrid TDMA/CSMA Multichannel MAC protocol to increase throughput. High throughput is achieved by eliminating unnecessary control overhead resulting in faster timeslot acquisition. Wang et al (2012) had already proposed Multichannel MAC scheme with Channel Coordination. They proposed variable control channel interval to provide reduced transmission delay. Then Cao et al (2017) 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. Steinmetz et al (2018) 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 (2016) 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.

For Simulation, AY Kurz (2014) proposed development of object oriented traffic simulation framework suiting the Lane based algorithm like CARA . Chen and Cheng (2010) gave overview of the agent based modelling applied on different types of traffic systems, including decision support systems along with congestion management. Dresner and Stone (2008) presented a multi-agent reservation-based algorithm which consisted of two types of agents: intersection managers and driver agents. Zou and Levinson (2003) calculated the impact of microscopic adaptive control on traffic collisions at Rounabout utilising multi-agent systems in ad-hoc network . Rakha et al. (2011) proposed the agent-based framework's integration for modelling various traffic scenarios. Jin et al. (2007) presented a hybrid agent based system for ITMS simulation that performs the services to optimize traffic management.

Algorithm for Lane Change in Roundabout

The proposed algorithm CARA assumes that basic building block any traffic scenario is Lane (2018). Therefore Roundabout is modeled with Two lanes viz. inner left and outer Right lane. Many segment are connected consecutively to analyse traffic system. Figure 1 depicts a Roundabout which has 2 lanes traffic system and Four connected branches at right angle to each other. Vehicle intending to go Left turn and going Straight would utilise outer lane. The vehicles which want to take Right turn or a U-Turn would use Inner lane. Initially we have a vehicle in leftmost side (West-in lane) and want to go south will travel through Wi going into WN and NE segment. Then it will use ES followed by South out to leave the Roundabout.

Figure 1. Shows a typical 2 Lane Roundabout



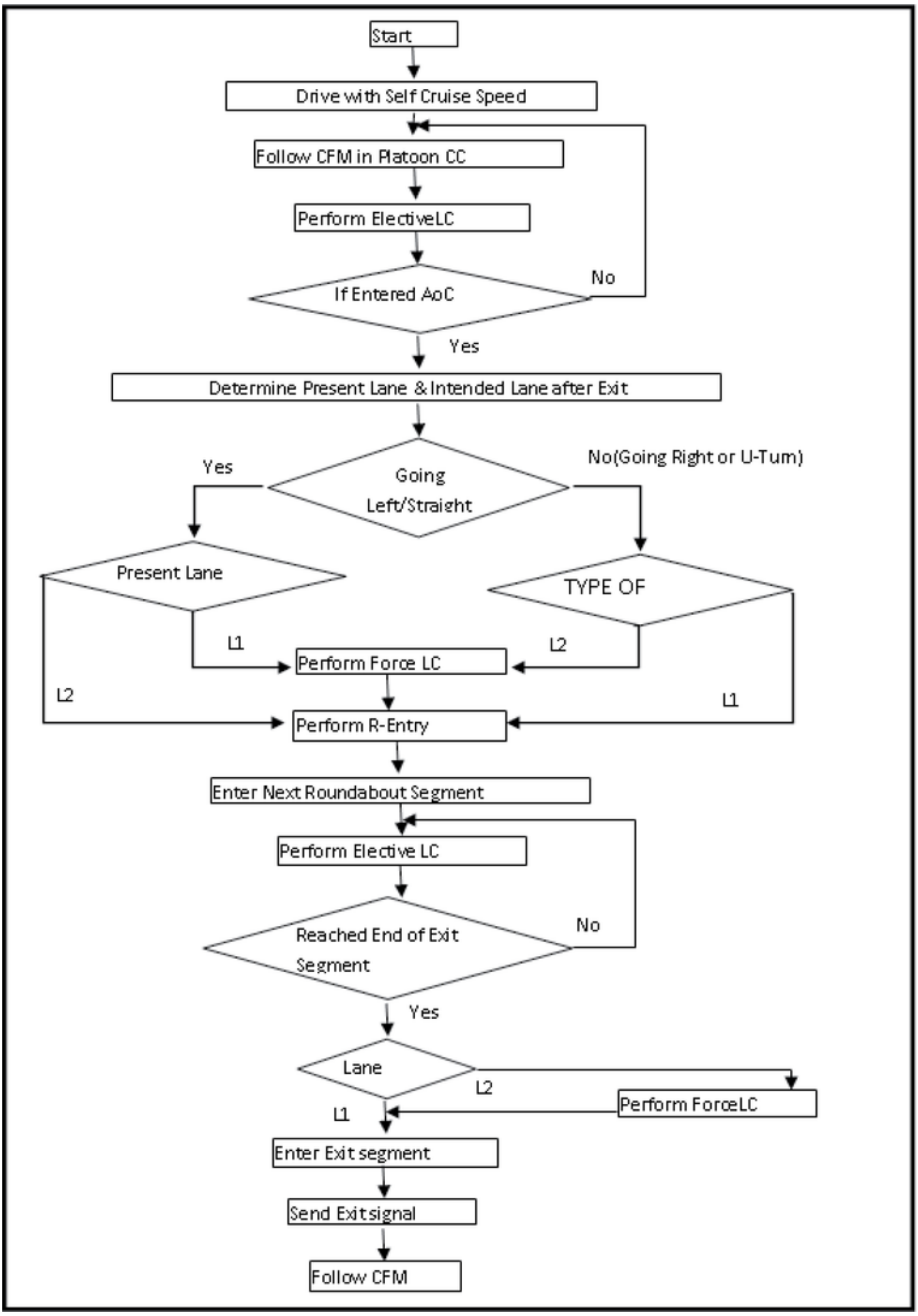
Collision Avoidance at Roundabout Algorithm-CARA

CARA (Collision Avoidance at Roundabout Algorithm) has been developed with ISU at its center. Here ISU is a agent checking for any impending collision by utilizing Simulators, it receives and then transmit messages to other vehicle in its Area of Responsibility (AoR). Whenever a car enters AoR of ISU will start strictly follow command from ISU rather than taking its own decision. At ISU the main algorithm CARA algorithm is sub-divided in following sub-algorithms:

1. **REntry:** Lane Insert for mitigating conflict at entry point of roundabout.
2. **RExit:** Lane Exit for safely exiting.
3. **ForceLC:** Force Lane Change algorithm within 50m of entry of Roundabout.
4. **ElectiveLC:** Elective Lane change algorithm.

Figure 2 give the flow chart of Main CARA algorithm describing coordination with other sub-algorithm. ElectiveLC, ForceLC, REntry and RExit sub-algorithm are subsequently described.

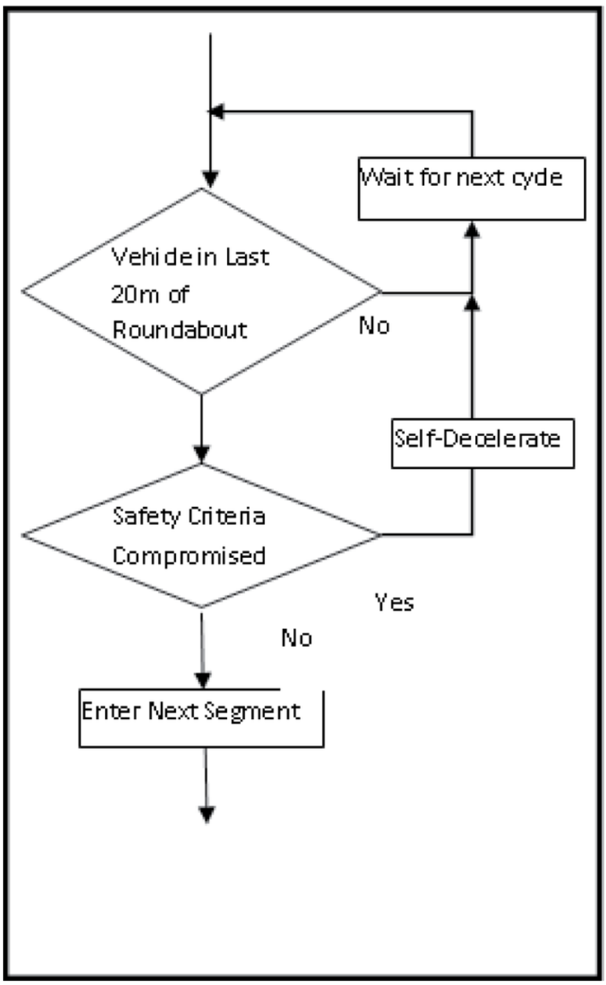
Figure 2. Flow Chart of CARA Algorithm



Algorithm for Entry Into a Lane at Inter Section

The algorithm LaneEntry is utilised to settle the contest between vehicle from different direction intending to merge. So in a roundabout there will be 4 major point of conflict at entry of 4 lane entering the roundabout. This is the very reason of dividing the roundabout in 4 Segments consisting of inner and outer Lane. For simplicity and safety we have utilised the time tested philosophy of FCFS scheduling algorithm. As per this algorithm a vehicle coming from artery lane trying to enter roundabout will wait by slowing down or decelerating. The vehicle which is already in roundabout will get priority over vehicle intending to enter, and therefore will continue to complete their journey at their own speed. So this vehicle will be injected in next lane with same speed. The vehicle intending to enter the Roundabout will be slowed down so as to ensure that when vehicle from artery road enters the lane there is minimum distance of vehicle length plus 5m between them. Here also the Lane change will be allowed only after 50m which is ample distance for any vehicle to settle down in its lane (Figure 3).

Figure 3. Flowchart for algorithm LaneEntry



Algorithm 1: REntry - At entry in Lane of Roundabout

```
Input: Present position of Vehicle with Lane Number
Output: Enter or Slowing down order
1.        End of current Lane (100m before end point).
2.        Enter into next lane.
3.        Check for Safe distance with roundabout vehicle
4.        If safe, vehicle from artery lane will enter into
          roundabout lane.
5.        If Not safe, reduce the speed by sending Deacel message
of Vehicle adjacent Lane.
```

At Exit of Roundabout

When a vehicle is approaching its Exit Lane, a compulsory Lane Change is performed, from inner lane to outer Lane. Here first the Route is checked to determine the correct Lane in which the vehicle should be at the end of the Roundabout segment through which vehicles is designated to exit/ leave the Roundabout. If vehicle is in correct lane i.e. in outer lane, it just moves in left lane of outbound artery road. Else if it is in inner lane at the exit segment of roundabout, it uses a Sub-algorithm Force LC, wherein it force vehicle in outer Lane to slow down and change the Lane.

Algorithm 2: RExit for Exiting from Roundabout

```
Input: Present position of Vehicle with Lane Number
Output: Lane change and Slowing Down order
1.        If End of current Lane (100m before endpoint)
2.        If in outer lane, change Lane going out of Roundabout
3.        If in inner Lane, perform Forced Lane change, Transmit LC
4.        Come in outer Lane and then enter Outgoing Lane of
Roundabout.
```

Detailed Algorithm for Elective Lane Change

The LC lane change algorithm which have two major part one which evaluates the need of lane change and others which evaluates the safety criteria. The benefit or the advantage of lane change is determined followed by fulfilment of safety consideration in form of Safe distance which is required for braking and bringing the vehicle to stop safely.

Algorithm 3: Elective LC for Elective /Optional Lane Change

```
Input: Present position of Vehicle with Lane Number, Target/
Adjacent Lane
Output: Lane change or Abort Lane change order
1.        50m crossed in present lane if Yes
2.        Check for a Feasible Gap in Adjacent lane
3.        If overlap with neighbouring vehicle Abort LC
4.        ELSE: Determine Potential /Likely successor on Target lane
5.        check for Gap (car length+5m)
6.        Get successor ID
7.        Predecessor ID- If available
8.        Create dummy vehicle BigM + SmallM(created for
```

Table 1. Message set and categorisation

S.N.	Message Set	Priority	Category	Description
a.	Abort LC	1	**SAFETY**	Abort the prior allowed Lane Change and Fall back
b.	DeAccel	2	**SAFETY**	De-accelerate by breaking
c.	Compulsory LC	3	**LANE CHANGE**	Perform the Lane Change mandatorily.
d.	Present Position	4	**INFORMATIVE**	Give present Latitude, Longitude, Speed, Breaking Coefficient, Total Weight with Load
e.	LC Authorised	5	**LANE CHANGE**	Lane change has been authorised by ISU with safety criteria fulfilled.
f.	Clear	6	**INFORMATIVE**	Roundabout has been exited by vehicle
g.	Lane After of Exit	7	**INFORMATIVE**	Intended Lane after Exit.

```
Exception for 1st or Last vehicle)
9.        Access Safety criteria
10.        Calculate New Acceleration of back Vehicle in Target lane
11.        Benefit-SV-Self vehicle. PVCL(Predecessor Vehicle in
Current Lane) & PVTL(Predecessor vehicle in Target Lane)
12.        Perform Lane change.
13.        Add Self Vehicle in target lane
14.        remove SV from current lane
```

Message Set

Now to implement our CARA algorithm, a prioritised Message list is prepared consisting of Message that are required to be communicateded with ISU The ISU gives choice to driver in certain situation and the driver can exercise his option if he desires so and can refute it also. Else whenever security is likely to be compromised like in case of Abort lane change (AbortLC) the driver has to implement it and therefore these messages are given highest priority. The complete set of Message Set is given in Table 1.

DESIGN OF RMAC (ROUNDABOUT MAC) PROTOCOL OPTIMISED FOR ROUNDABOUTS

The job of Intelligent crossing/Roundabout 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. Safety related message may transmission is an effective way to contain life critical information, it is a necessity that the sender as well as the message 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 communication process in this protocol happens in two phases. In first phase cars that have any packet ready to be transferred makes a request to ISU. In second phase depending up on priority of type of message, ISU will assign the channel to this car. The channel contention is managed by the ISU by allocation channel on Assignment band. As the channel are allocated/ assigned by ISU, probability of collision among request packet is very low. This type of channel assignment falls under the category of Centralised MAC protocol. Here the ISU controlled frequency allocation protocol is able to solve problem of the exposed node and hidden node. Here the complete frequency spectrum has been divided in three band namely:

1. **Assignment Band (AB):** Assigns the channel on request;
2. **Road Band (RB):** It caters for vehicle travelling in cloves of Roundabout (On Road used by Vehicles for Entering and Exiting Roundabout);
3. **Round About Band (RAB):** Used for controlling vehicle while they are in Roundabout.

Also each frequency band is further sub divided in number of Timeslots (say Eight we have used in our Simulation). So an Logical channel comprise of a Frequency band and Time slot. Dynamic allocation of Time slots/ Channel. Since number of vehicle in roundabout area can not exceed a fix number, we can approximately divide the slots. As number of vehicle cars entering the roundabout area keep on increasing, the time slot will keep on reducing. Similarly as cars keep on exiting the roundabout area, the time slot will keep on increasing.

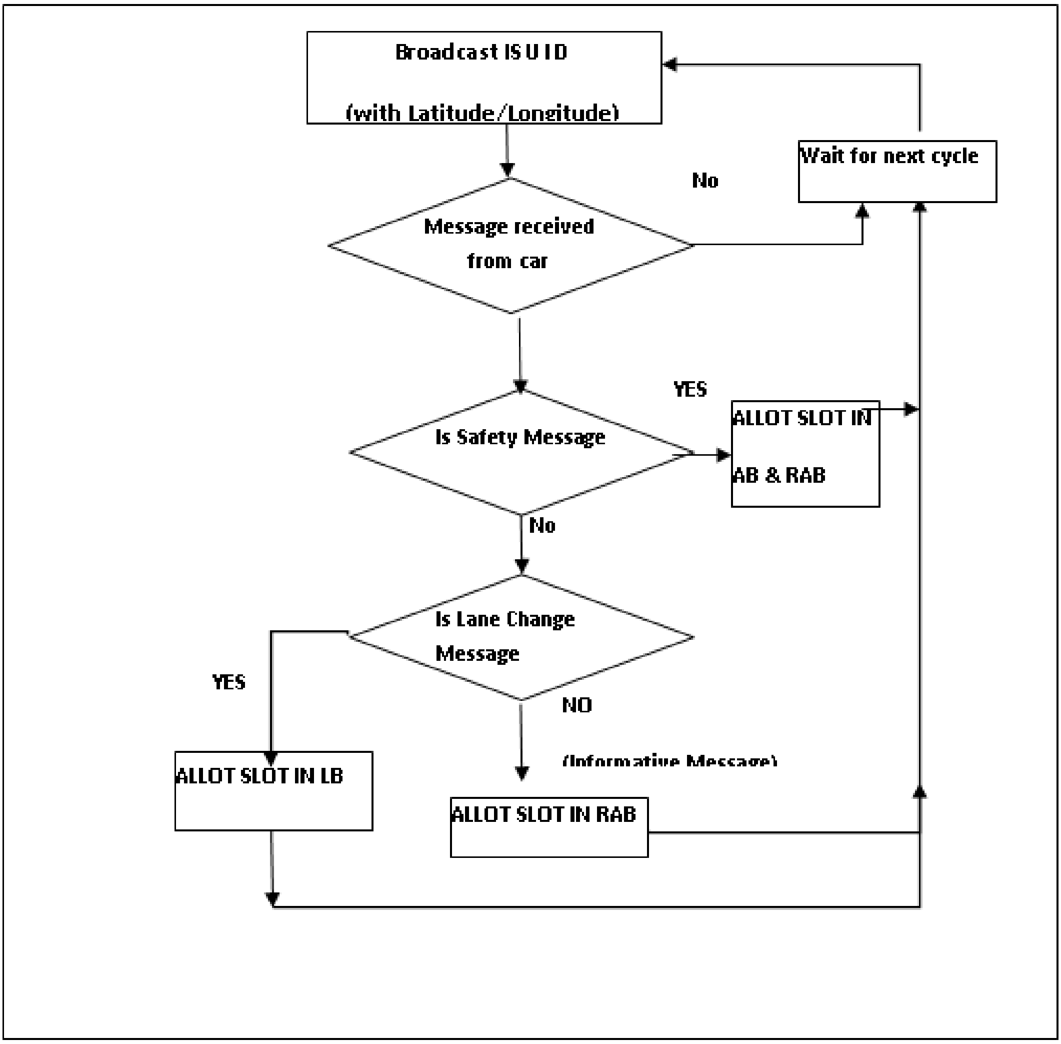
The flow of operation of our designed RMAC protocol at the ISU is presented at Figure 6. The functioning of the proposed MAC protocol is as depicted in flowchart at Figure 4 which is executed at each of Vehicle agent.

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 Roundabout 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.

Algorithm for Intersection Specific Channel Access for VANET

Step 1: ISU broadcasts the beacon message its ID through Assignment channel while cars will continuously monitor this channel .
Step 2: As the vehicle enter into ISU control range 1500 meters in our case, it sends a association request
Step 3: ISU sends a confirmation message taking over control of vehicle.

Figure 4. RMAC Protocol operation at RSU



Step 4: Depending on vehicles geographical location, ISU assigns Road Band or Roundabout band for communication.
Step 5: 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.
Step 6: ISU will maintain three register viz. Safety, Lane Change or Informative and will allocate channel on same priority.
Step 7: For additional Safety channel will also be allocated on Assignment Band if it is a request for Safety type of message.
Step 8: Message list of Informative Type will get allocation only when Safety as well as Lane change type of message list is empty
Step 9: Car will send transmission complete packet to ISU.
Step 10: ISU

MODELING AND SIMULATOR

RoundSim

The Simulator RoundSim is developed specifically for Simulation Roundabout Traffic. This Simulator can give output in form of Text output, Graph of Video output for better understanding and comprehending the controller protocol. Figure 5 shows a snapshot of RoundSim Simulator.

Test Setup and Experimentation

The test set-up was implemented in Python language which is a OOPS (object oriented programming) and therefore helps in studying interaction of RSU to Cars. Here cars are the multi agents which incorporate mechanical as well cyber level hardware viz. communication equipments. Here each car can be seen with their Entry and exit lane numbering.

ISU is main controller and all other cars are agents which it is controlling in its area of responsibility. 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.

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 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 roundabout section.

For simulation of communication protocol following parameter were used and given in Table 2.

RESULT AND ANALYSIS

The graph vide Figure 6 depicts the results of traffic at roundabout where cars and control at ISU are implementing CARA protocol. The result proves that due to lane change there is a 60% improvement. As Figure 6 depicts the average delay time experienced by vehicles with increase in vehicle density.

Figure 5. Snapshots of RoundSim

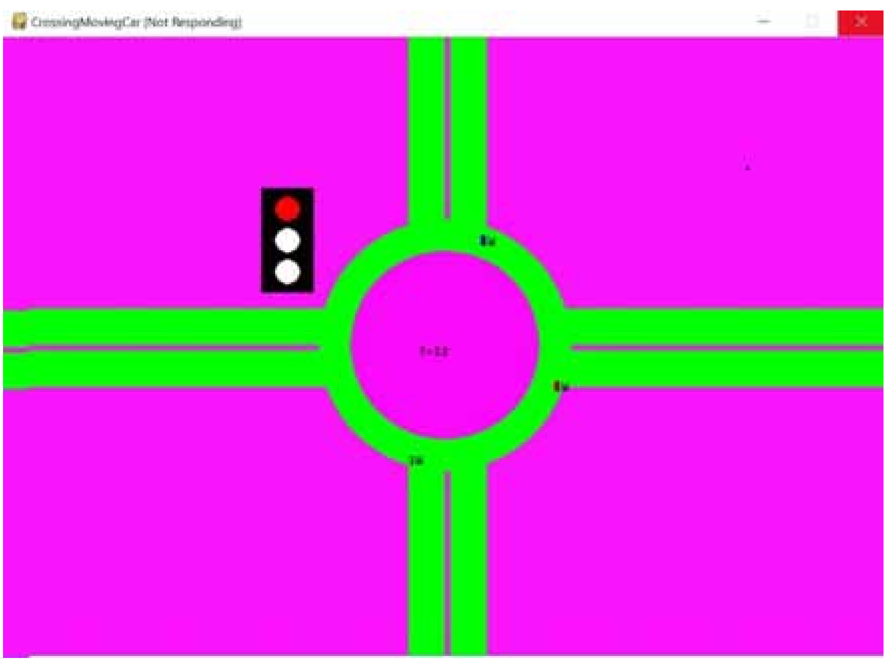
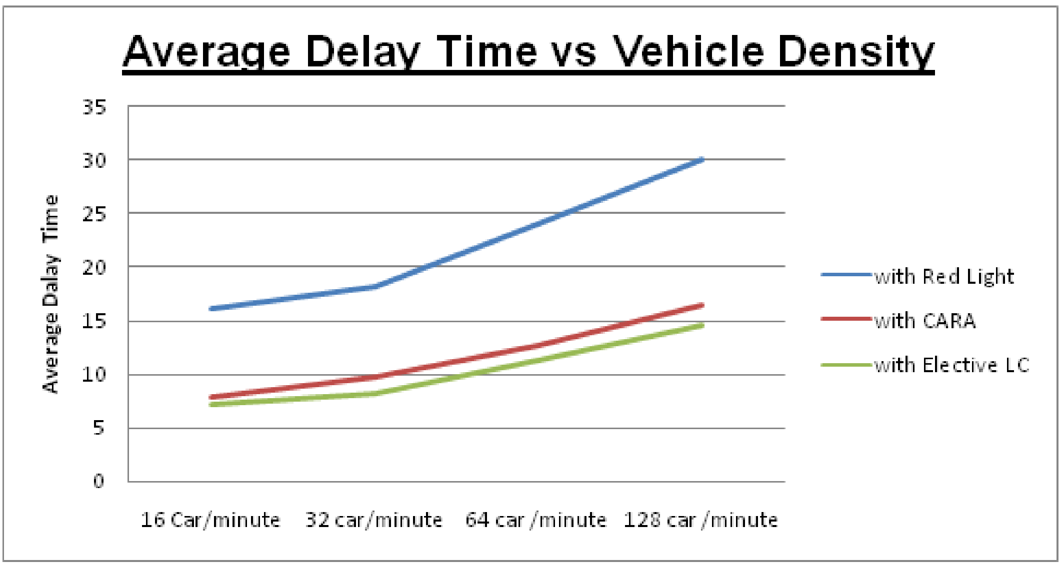


Table 2. Simulation parameters

Number of vehicle	16,32,64 and 128
Data rate	2Mbps
Packet	UDP
Traffic Type	CBR
Packet Size	Variable(20,50,100 bytes)
Packet generation rate	10 packet /sec for ISU
Transmission range of ISU	1500 m
Transmission range of Cars	500
Vehicle Speed	30 and 60 km/h
Simulation Time	5 min
Antenna Type	8 Antennae Highly Directional Type

Figure 6. Average delay time vs. Vehicle density



Simulation done under three control regime at Roundabout shows that delay time considerably reduced with CARA algorithm. There is also marginal improvement with ElectiveLC.

The Figure 7 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 inline with our hypothesis that CARA with ElectiveLC will increase the throughput.

Analysis of RMAC Results

The Figure 8 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 can be seen that the packet reception ratio

Figure 7. Average queue Length vs. Vehicle density

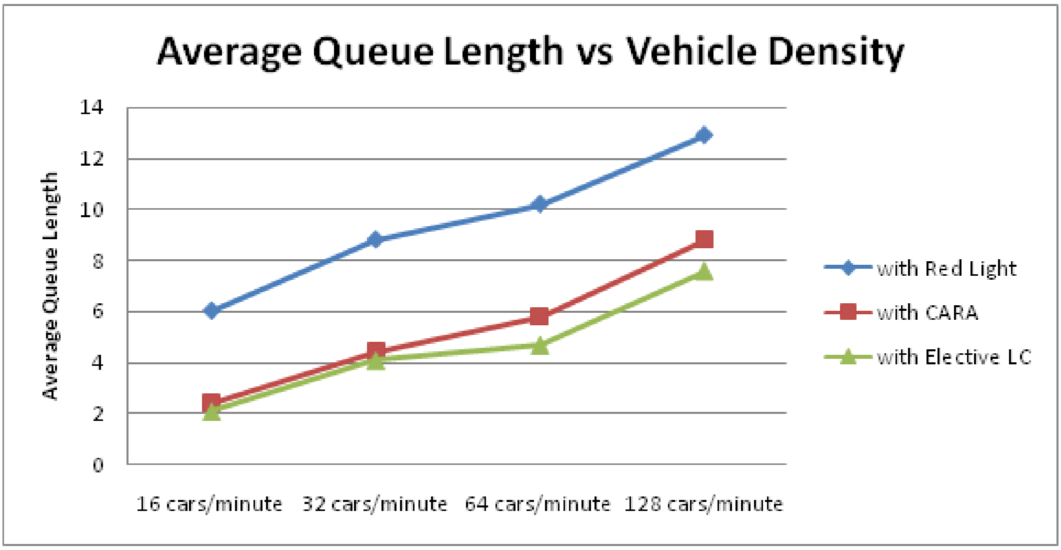
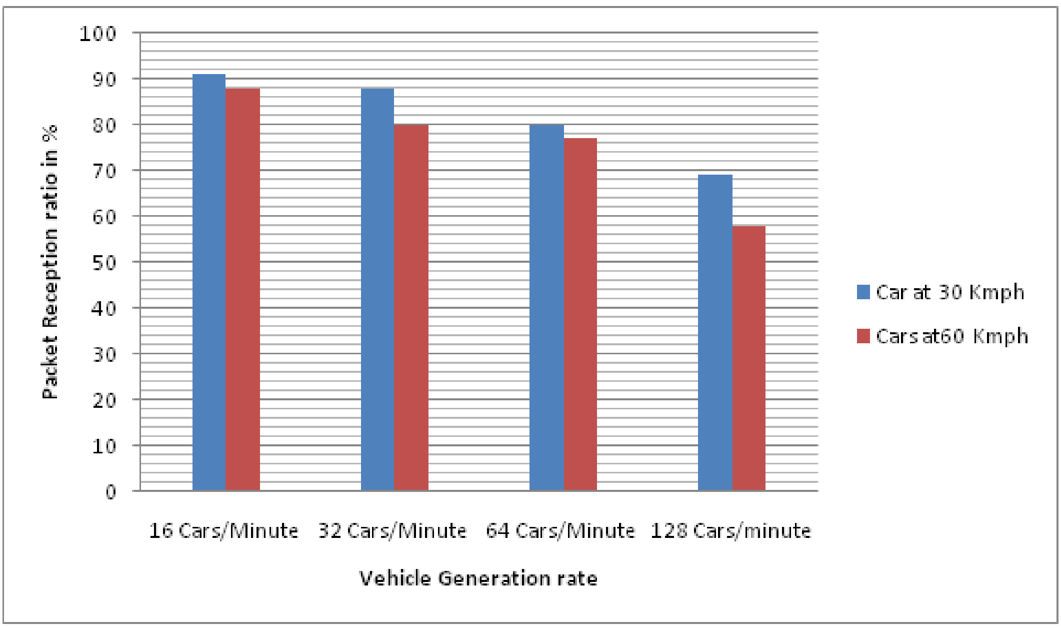


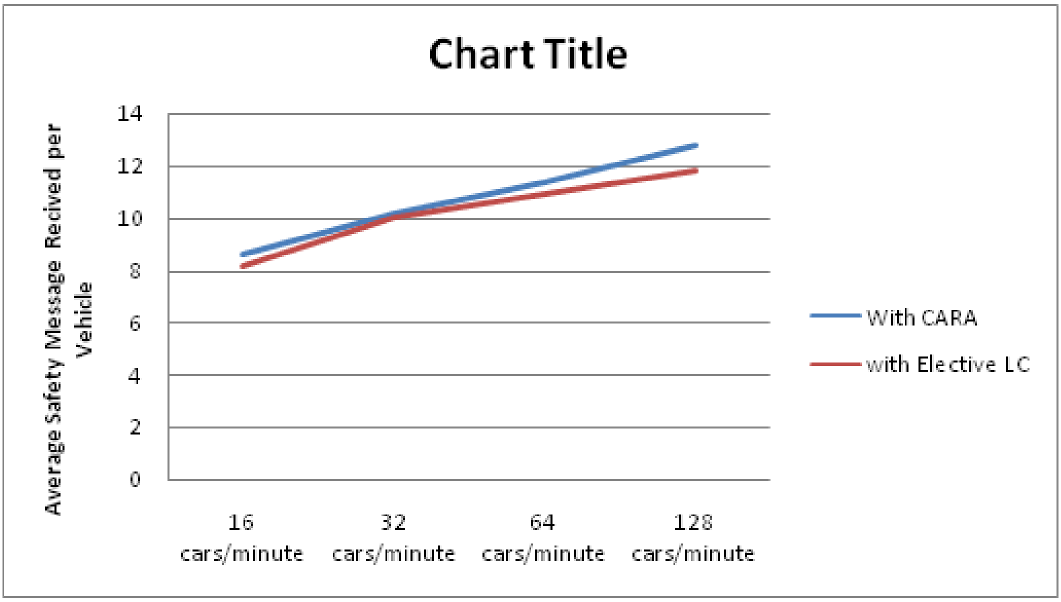
Figure 8. Packet reception ratio vs. Car density



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 9 describes the average number of safety packet received by each vehicle with respect to number of vehicles generated per minute. As it is evident that as the number of vehicles increases the number of packets received also increases. This is because the vehicles has to change its lane before

Figure 9. Average safety message per vehicle received vs. Car density



entering Roundabout. Also once in roundabout the number of message required for navigation will increase. Than plot was drawn with ElectiveLC, which has reduced the number of messages required. This has been possible because of higher throughput of CARA algorithm with ElectiveLC.

CONCLUSION

We know that Smart Transport is also an integrated part of healthcare technologies. To minimize the pollution for benefiting the healthcare, the Traffic throughput on Roundabout intersection has to be increased which will reduce wasted time and will also enhance passenger comfort. The time taken by a vehicle to cross the Roundabout has to be reduced for increasing the throughput of intersection. 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 CARA 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/roundabout. 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.

The MAC protocol in VANAT plays one of the most critical role for safety in ITMS. The proposed work of CARA (the traffic controlling protocol) combined with new MAC communication protocol will help in increasing safety as well as Comfort of passengers. This will increase the capacity of intersection area both in Crossing as well as Roundabouts. The proposed designed MAC Protocol helps in reliable communication for ensuring Safety in ITS. Different safety message containing the both acknowledgment and emergency detection have been designed with different Priority Scheme. Its affect on fundamental challenges such as message redundancy, hidden terminals and broadcast storms, which greatly degrade network performance has been studied. In future this efficient protocol will be energy optimised. The Effect of fading and no. of user on the performance of MAC protocol will also be studied.

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