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An Efficient Emergency Vehicle Clearance Mechanism for Smart Cities

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Abstract

The transportation management system is becoming an overwhelming task across the globe due to Globalization and population growth. Increased traffic congestion poses several problems. The extended waiting time at traffic jam leading to air and noise pollution due to the amassed vehicle is a serious threat to human health and the environment. This situation aggravates the clearance of any emergency vehicle resulting in grave consequences for the patient. A better control over the transportation system can be achieved through the Internet of Thing (IoT) based smart infrastructure. To deal with such emergency situations, this paper proposes a framework for automatic emergency vehicle clearance system. Traffic signal dynamically suspends the routine movement of traffic flow to create a "Green Corridor" to pass the ambulance without any delay at the traffic junctions. IoT based RFID tag and reader at vehicle and traffic junction respectively is used to identify the ambulance at the traffic junction. The work is simulated in SUMO and detection of RFID is analyzed in NS2 with the integration of SUMO. Considering the criticality of the issue, a simulation of the proposed work does not suffice. Therefore to check the robustness of the proposed system, it has been tested in a laboratory environment. The average reduction in travel time for five different simulations for an emergency vehicle from source to destination is 254.6%, which is substantial.

Keywords : Emergency vehicle, Green Corridor, RFID, Smart traffic management, SUMO, Traffic congestion

I. Introduction

Smart city is the most popular term used for urban development in developing nations. The vision of a smart city is to provide effective and technologically sound amenities for the people who reside in these cities. The need for smart cites arises due to population growth and urban mobilization. The movement of people toward urban cities and the movement of the people residing within the city lead to more number of vehicles on the road. The increase in the number of vehicles leads to congestion and causes a traffic jam. This becomes a major issue that affects the quality of services to be provided for its citizens. Some other problems related to transportation are environmental pollution and non-availability of parking space for vehicles.

The biggest issue related to transportation is related to the exit of emergency vehicles in case of traffic jam. Emergency vehicles, like ambulances, fire-fighting vehicles or police vans need to reach the destination in the shortest time so as to avoid the loss of life or loss of goods. These vehicles need to be cleared from the traffic light junctions as quickly as possible. It is a known fact that the possibility of survival of victim(s) is significantly increased by providing emergency medical treatment as soon as possible. Currently, in many nations, any emergency vehicle approaching toward the traffic junction is dependent on the audible and visible alarming system to alert others. This alarm system has a confined distance from which it can be sensed. The situation becomes more complicated when there are multiple emergency vehicles arriving at the same time. It's very difficult to identify the direction of the arrival of an emergency vehicle. This conventional method is not suited for congested areas but still finds its use as a standard mode of operation.

A recent survey [XI] revealed that life of nearly 18000 patients could have been saved if they had reached the hospital in time and received the medical treatment. This article proposes a method to create a "Green Corridor" for the clearance of emergency vehicle in a smart and cost-effective way. The proposed method employs RFID reader installed at traffic junctions to read the RFID tags of vehicles. This data is sent to a Traffic Control Server (TCS) for processing. Any emergency vehicle equipped with the RFID tag is detected at traffic junction having RFID reader. The TCS alerts the next traffic junction in advance so that the next traffic junction suspends the normal flow of traffic and creates the traffic movement for the clearance of the emergency vehicle. After passing this emergency vehicle, traffic junction resumes normal flow of traffic and this process is continued until the vehicle reaches its destination.

The remainder of this article is organized into five sections. Section II summarizes the literature survey. In section III the proposed work has been discussed. Section IV provides the simulation result and hardware implementation and finally, section V concludes this paper.

II. Literature Survey

The increased traffic congestion has brought a lot of awareness in the research community that aims to provide an innovative solution to save time, money and human life. In the case of a medical emergency, the situation became more pathetic and people lose their life. For clearance of the emergency vehicle, many researchers [III, V, VII, XV, XXIII] propose an emergency vehicle clearance system based on acoustics. To alert the traffic junction and other people, the emergency vehicle uses a sound-based alarm system. In this system, accurate location and direction of movement of the sound-based alarm system in emergency vehicles are very difficult to identify by traffic cop at the traffic junction. Several approaches have been proposed for image-based [VIII, IX, XVIII, XX,] traffic monitoring for estimating the congestion on the route. Prior information of congestion helps the Traffic Control Server to make arrangement for the emergency vehicle. Nellore and Gerhard [XII] propose a visual-based emergency vehicle clearance that uses a camera to identify the emergency vehicle. A mathematical model is used for calculating the distance between the identification point of vehicle and traffic junction. The over speeding of the other vehicle creates a problem for the ambulance. Kumar, Sachan, and Kushwaha [XXII] propose an image-based framework to detect the high-speed vehicle. An image-based Congestion of detection technique is proposed by Kumar and Kushwaha [XXI]. A camera installed at traffic junction is used to extract the frame of the two consecutive relative positions of the vehicle. Image-based monitoring system suffers from performance degradation due to environmental conditions [XII-XIV].

IoT based traffic control system [IV, XIX] is proposed for emergency vehicle clearance. The system uses GPS for predicting the location and congestion on the road. It is very efficient and accurate but the installation cost is very high making it unviable for many under-developed countries. In the research paper by Smith et al [VI], they evaluate the impact of the random road incidents on the travel time of the commuters and the overall traffic congestion under certain scenarios. They evaluate the impact of traffic congestion due to road incident and is simulated in SUMO. The results obtained are used for rerouting of vehicle. Mittal et al. [II] propose a green wave approach for emergency vehicle to make a smooth passage at a traffic junction without any delay. To setup, a "Green wave" synchronization of traffic light is done in such a way that the entire path is reserved for the emergency vehicle. The major flaw of this technique is that it blocks the entire route for emergency vehicle by turning on all the traffic light green. Chattaraj et al. [I] propose a system to identify the vehicle and its speed by using two RFID installed at some distance before the traffic junction. Vehicle is identified by its unique code and distance is calculated by time difference between two consecutive RFID readers. Sharma et al. [XVII], propose an approach to prioritize the traffic light for emergency vehicle by using RFID. RFID is used for multilane, multivehicle and multi road junction area. This approach requires the traffic police to emulate the signal in real-time. Sunder et al. [XVI] propose a method for emergency vehicle clearance that uses a ZigBee transmitter fitted in an emergency vehicle. This transmitter is used to send the unique code to ZigBee receiver installed at traffic junction. At receiver side, the unique code is used to match with the database; if code is matched then green light is turned on. ZigBee is cost-effective and has the capacity to communicate with the receiver at a range of 20 meters. In a real-life scenario, the average speed of the emergency vehicle is approximately 60 Kmph, so vehicle takes only 1.2 second to reach a traffic junction during this range of 20 meters. During high traffic congestion, the ambulance may not be able to connect with the receiver due to the long queue of the vehicle near the traffic junction. In order to overcome these challenges, this paper proposed a novel and cost effective IoT based approach that uses RFID tag and reader to create a "Green Corridor" where emergency vehicle is allow passing through intersection without any delay. This work also simulated in SUMO. For establishing the results obtained during simulation, the hardware implementation of the proposed system is also done. Further, the detection of RFID tag and reader at the traffic junction is simulated in NS-2 simulator.

III. Proposed Work

This paper proposes a novel approach for emergency vehicle clearance. In the proposed approach, a "Green Corridor" is created for the clearance of the emergency vehicle to allow for smooth passage of the vehicle in case of traffic congestion.

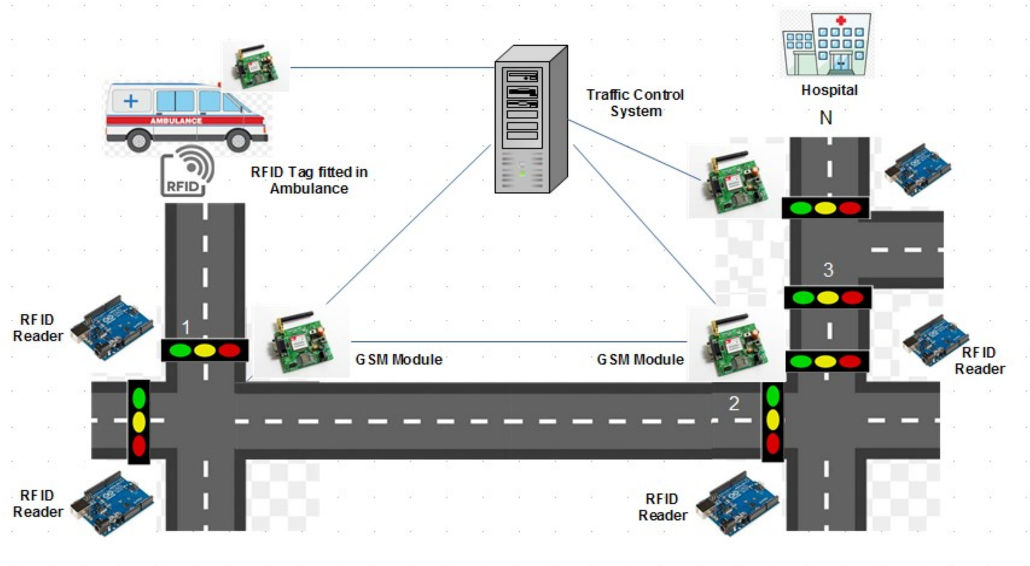

Fig. 1.Architecture of proposed system

A green corridor is a sequence of green signals for the allocated vehicle from source to destination. An RFID is fitted in the emergency vehicle and RFID readers are installed at every Traffic Junction. All traffic junctions are connected to a Traffic Control Server as shown in Fig. 1.

All Traffic Junction is connected to Traffic Control Server. The Traffic Control Server (TCS) can be deployed at the traffic control room of the city. A normal four-way Traffic Junction comprises of different information capturing, processing and transmitting devices and has four different traffic light signals (traffic lane) labeled as 1, 2, 3 and 4 as shown in Fig. 2.

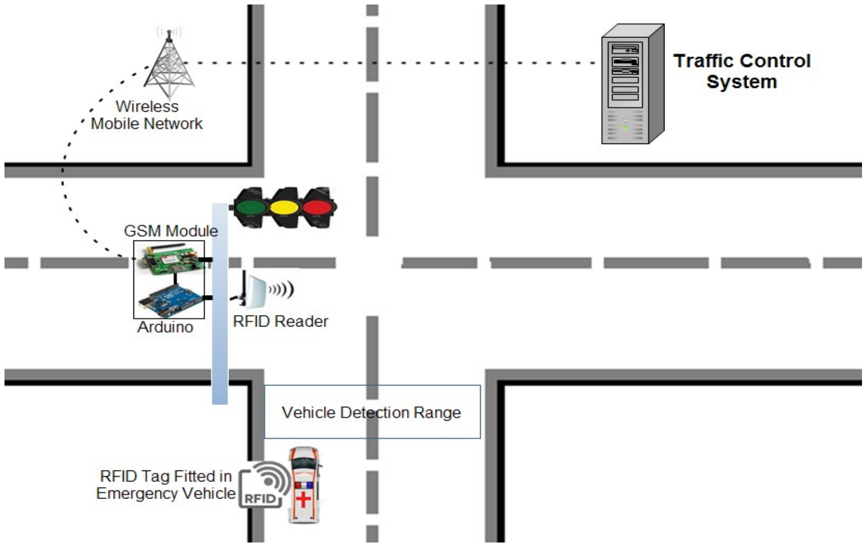

Fig. 2. RFID Tag and Reader Connected to Server

Four different RFID readers (data capturing device) are installed near the traffic light. Each RFID reader is used to detect any vehicle including the emergency vehicle that passes through the corresponding reader's range. The RFID reader is used to fetching the vehicle information from the RFID tag installed at the emergency vehicle and vehicle detection time-stamp. This information is processed through a microcontroller (Arduino). A GMS module, that uses a mobile network to communicate with the TCS, sends the vehicle detection time-stamp along with the Vehicle Unique Identification (VUId) to next Traffic Junction.
Collaboration diagram of message flow is shown in Fig. 3.

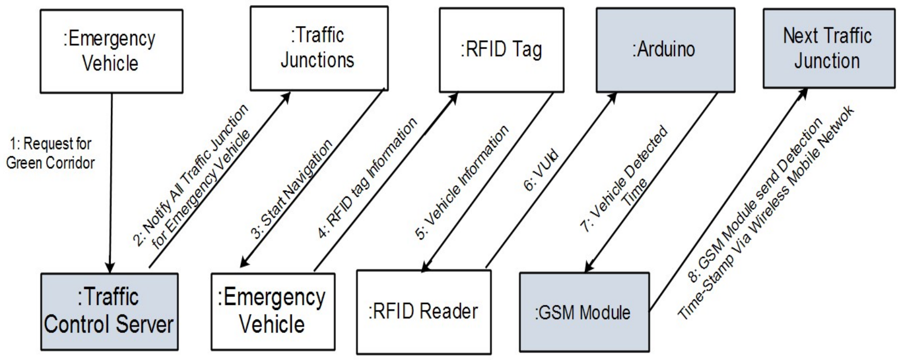

Fig. 3. Collaboration diagram of message flow

There are two major modules in the proposed approach. First is to design a route plan on receipt of a request for Green Corridor and execute the route plan in order to provide a barrier-free path. Responsibility of the first module lies with the Traffic Control Server (TCS) that generates a route plan for the Green Corridor based on the request made by the emergency vehicle. The TCS comprises of five major components namely Request Handler (RQH), Route Finder (RF), Response Handler (REH), Vehicle Authenticator (VA) and Traffic Data Processing Server (TDPS). The constituent components that generate a route plan for the Green Corridor generation are shown in Fig. 4.

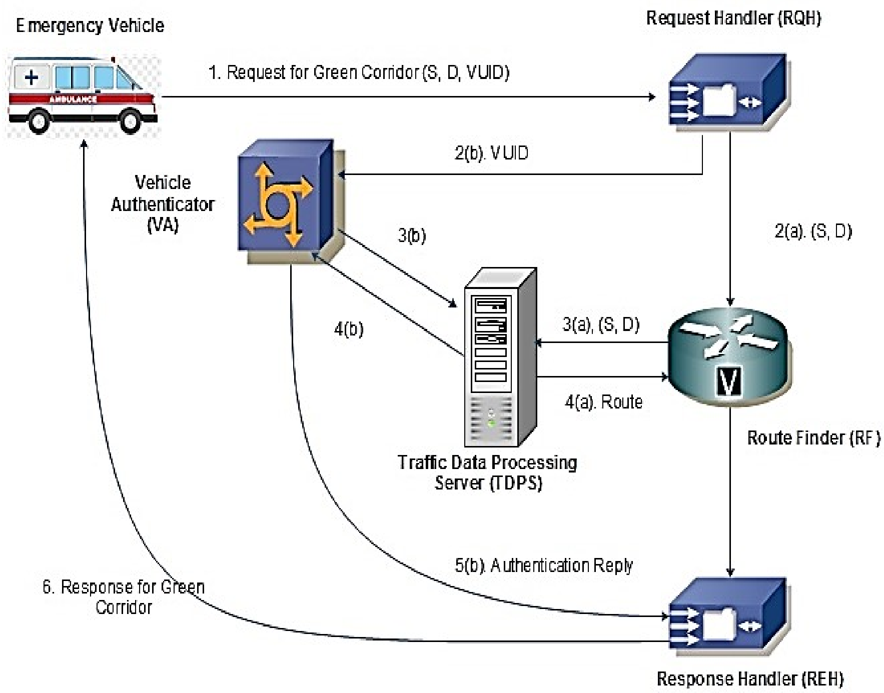

Fig. 4. Route plan generation for the Green Corridor

The emergency vehicle sends a request for Green Corridor to RQH module. This request contains information about the Source (S), Destination (D) and Vehicle Unique Identification (VUId). RQH module invokes RF to find a route from S to D. RF sends the route information to TDPS module which returns the route plan to RF. Simultaneously, REH sends the VUId to VA for identification of the emergency vehicle. VA authenticates the emergency vehicle based on the record stored in TDPS and sends an authentication message to REH. REH module receives the route information from RF. This route information contains details about intermediate Traffic Junctions, which are stored in a route array TJ [N], where N is the number of intermediates junction. Finally, REH generates a response that is sent to emergency vehicle only if the vehicle is authenticated by VA. The response message contains the route plan for the Green Corridor. Now the emergency vehicle has details of the route for Green Corridor.

Upon receiving the route details, the Green Corridor should now be made available for the passage of the authenticated emergency vehicle. This is done by the second module. TCS issues an alert message to all the subsequent posts in the route about the arrival of an emergency vehicle (say ambulance). The first traffic post nearest to ambulance labeled as '1' in figure 3 sets it signal to green so that the emergency vehicle can pass through the traffic junction without any delay. In the proposed approach an RFID tag fitted in the emergency vehicle contains 12-bit Electronic Product Code (EPC). This EPC is used to fetch and store the identification information of the emergency vehicle. RFID reader installed at the traffic junction identifies the emergency vehicle by RFID tag fitted in the vehicle. RFID readers transmit electromagnetic waves which are sensed by RFID tags. In response, the RFID tag sends the identification information.

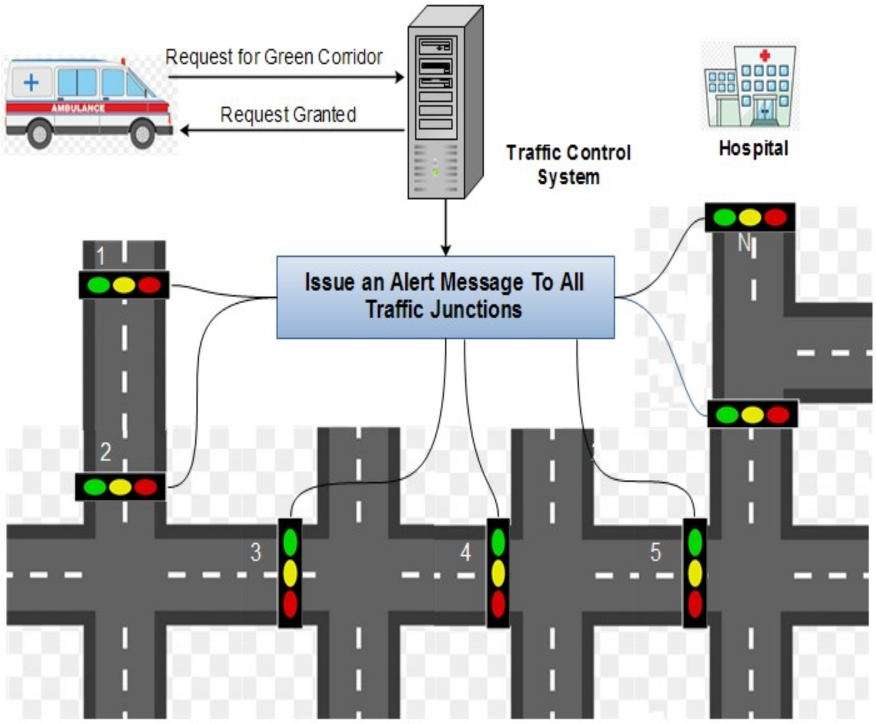

Fig. 5. Green Corridor creation

As illustrated in figure 5, when a vehicle arrives at the first traffic junction of its route, the RFID reader at this junction sends the vehicle detection timestamp to the next immediate next Traffic Junction that falls in its route map through the GSM module devices. As soon as the emergency vehicle crosses this traffic junction, normal traffic flow is resumed. After getting the time stamp, again the next Traffic Junction (second) sets it signal green for the emergency vehicle to pass through as shown in Fig. 6. This process is repeated until the emergency vehicle reaches its destination.

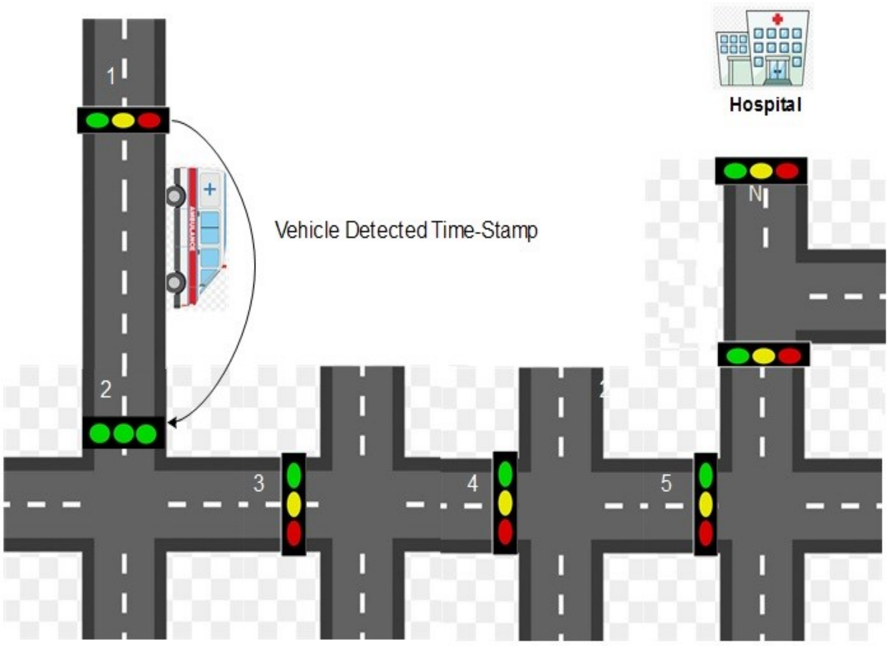

Fig. 6. Vehicle movement in Green Corridor

In the proposed algorithm, the emergency vehicle sends a request, which contains current location (Source), Destination where vehicle has to go and VUId. TCS is always at listening mode and at the arrival of request, it updates the vehicle information i.e. VUId, current location and destination. TCS matches the VID with its database and after verification, provides the route information to the requesting vehicle and at the same time it also intimates the entire intermediate traffic junctions between source and destination with the authorized vehicle's VID. The first traffic junction TJ [0] turns its signal green when it receives VID from TCS. TJ [0] is green till the crosses TJ [0]. After identification of the ambulance, the information and time stamp are sent to next traffic junction TJ [1] and TJ [0] resumes its normal traffic flow. This process is repeated until the ambulance reaches the hospital. The proposed algorithm is shown in figure 7.

Algorithm:Set up and Execution of a Green Corridor

FunctinonGreenCorridor(Source, Destination, VUId)
Intiliazation : S ← Source
D ←DestinationCordinates of source and destination location retrived from GPS
Output :TJ[ ] ▷ Route array

1: EV request for **route** to TCS ▷EV: Emergency Vehicle
2: **if** (TCS grant the request) **then**
3: TCS Provide route to ambulance
4: All traffic junctions are notified by TCS with a VUId
5: TJ [] ← Route details of 'N' junctions ▷ where N is numbers of junction between S and D
6: j ← 0;
7: TJ [0] sets its signal green
8: **while** j < N **do** ▷ loop continues until EV reaches destination
9: **if** (j!=0) **then**
10: TJ [j] sets its signal to green ▷ normal traffic flow suspended for jth traffic junction
11 **end if**
12: EV passes throughTJ [j]
13: **if** ($VUId_{EM}$ == $VUId_{TCS}$) **then** ▷ RFID reader at TJ [j] identifies EV
14: Send detection timestamp of EV to TJ [j+1]
15: Resume the suspended traffic to nornal state
16: j ← j+1
17: **end if**
18: **end while**
19: **end if**
20: **else** repeat steps 1 & 2

Fig.7. Proposed algorithm

The flow diagram of proposed approach is shown in figure 8.

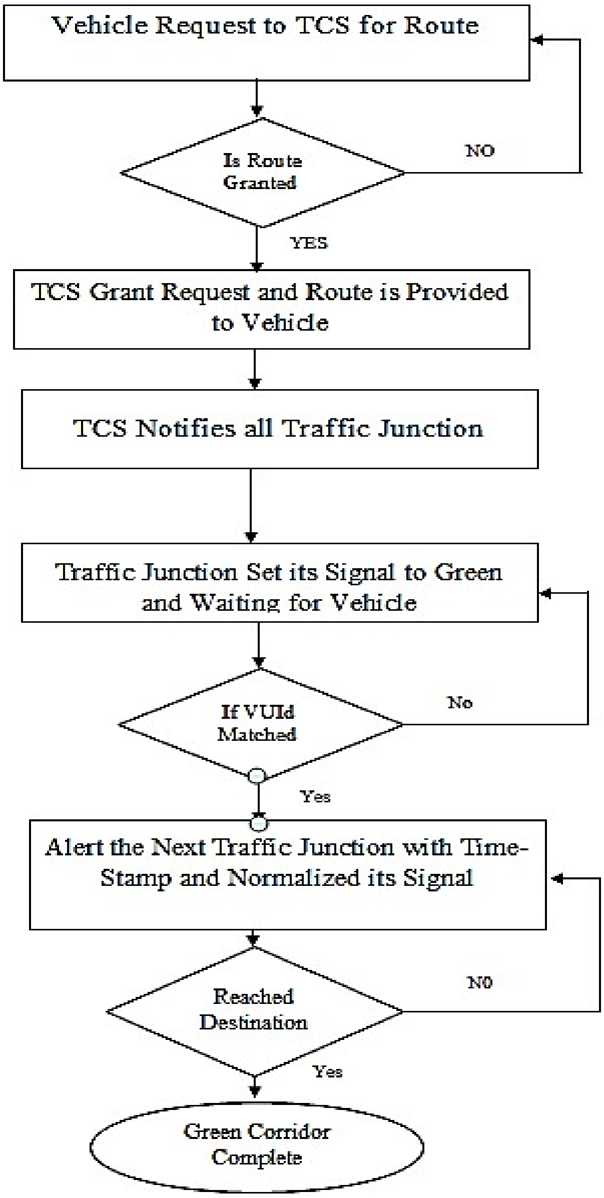

Fig. 8. Flow diagram for the proposed approach

IV. Experimentation and Result

The evaluation of the proposed approach is done through NS2 and SUMO based simulation and hardware implementation. The proposed approach requires the simulation of the detection of RFID tag in vehicles and setting of the Green Corridor. The experiment has been carried out in three steps to check the efficiency of the proposed approach. In the first step, the detection of RFID tags is simulated via NS2, which uses real traffic generated in SUMO. In the second step, the proposed approach for the creation of the Green Corridor is simulated in SUMO. In the final step, an experiment is performed with Arduino microcontroller to validate if it detects RFID tags and passes the signal to the next traffic junction for creation of the Green Corridor.
The three experiments have been discussed in the following subsections.

Simulation Analysis of RFID Detection

The efficiency and effectiveness of the detection of RFID tags are tested through the NS-2-based simulation with the integration of SUMO. For this purpose, a road map of a randomly selected locality in Bangalore, India (as shown in Fig. 9) has been imported in SUMO. The RFID readers are installed at various traffic junctions in the road map.
Further, RFID tags are attached to the NS2 nodes. These nodes act as vehicles on the road map. RFID reader records the movement of the vehicle, which passes through the associated traffic junctions. The parameters such as response time of RFID readers, the accuracy of tag detection, and the tracking of vehicles' route have been recorded.

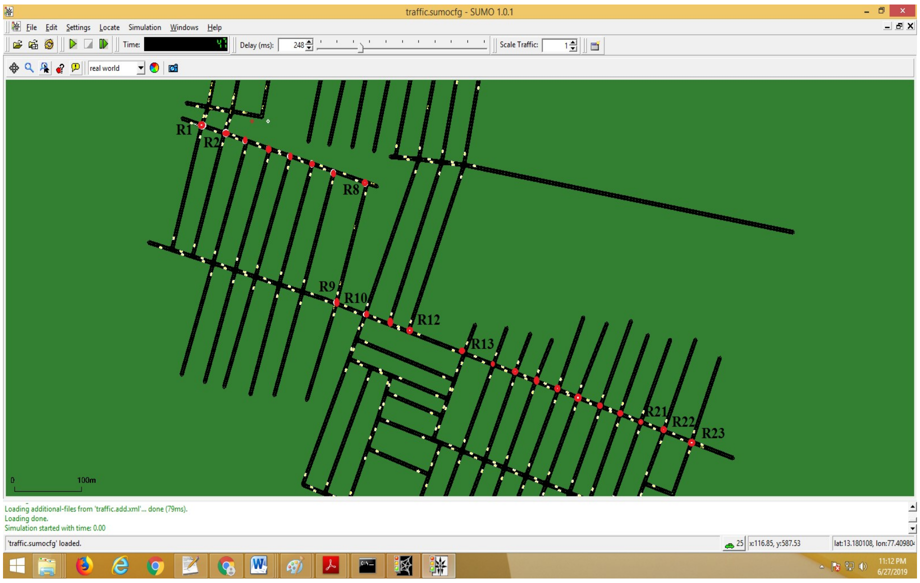

Fig. 9. Real map imported in SUMO

In Fig. 9, there are 23 RFID readers installed at various junction points across the city. The mobility of the vehicles and the position of the RFID readers are imported into NS-2. The node numbered 24 in figure 10 represents the vehicles having RFID tag number T1. The RFID readers are installed at various Traffic Junctions, which is denoted as R1, R2, ..., R23 in the figure 10.

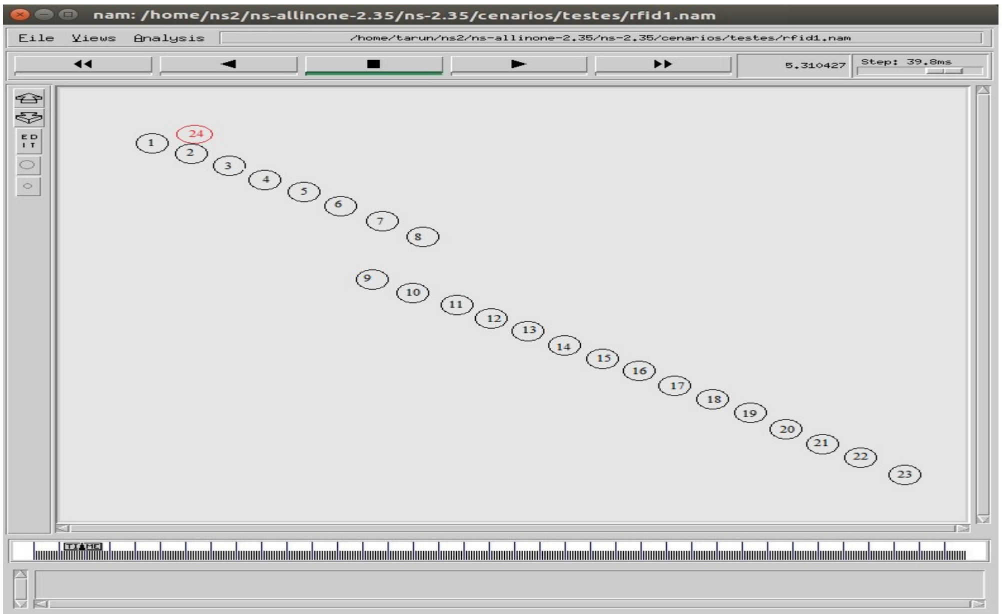

Fig. 10. Snapshot of simulation of the proposed approach in NS-2

The average time to detect the RFID tag and the accuracy of RFID readers are recorded during 5 different iterations. In each iteration, the number of vehicles with RFID tag are increased. Table 1 shows the Mean Time to Tag detection (MTTD), Standard Deviation (SD), and the Confidence Intervals (CI) of the RFID reader in different simulation scenarios. The Confidence interval is calculated as

C.I = MMTD $\pm$ $\boldsymbol{\alpha}$ *(SD/ n) , the value of α = 1.96, as sample accuracy is more than 95%.

Table 1: Analysis of the MTTD

S. No.	Number of vehicles (n)	MTTD (in sec.)	S.D.	Confidence interval (α=1.96)
1	2	0.21	0.0141	0.2109-0.211
2	5	0.23	0.0109	0.230-0.231
3	10	0.27	0.0194	0.267-0.273
4	20	0.24	0.0276	0.232-0.241
5	30	0.23	0.0257	0.229-0.233

Fig. 11 illustrates the comparative analysis plot of mean time to tag detection, standard deviation that is very less and confidence interval.

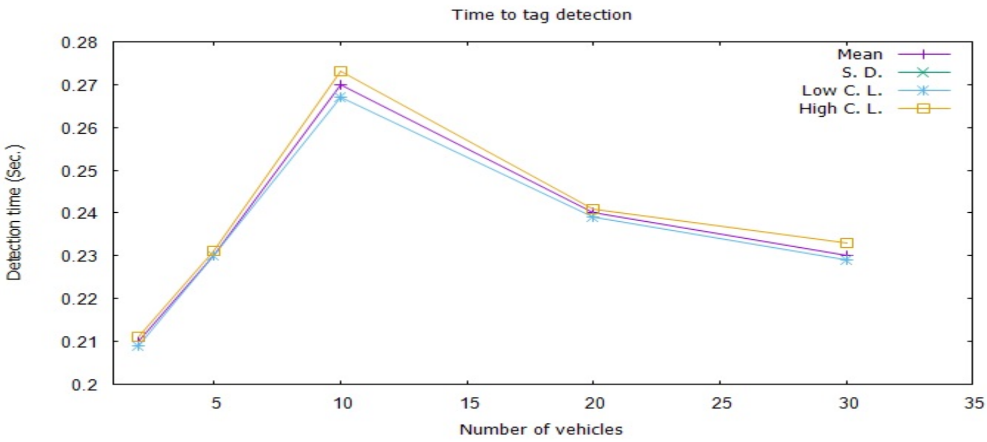

Fig. 11. Analysis plot of the MTTD of RFID Reader

The detection rate of the vehicle is 100%, and the average tag detection time is less than 0.5s, which concludes an adequate performance during the deployment.

Simulation of Vehicle Movement at Green corridor

The proposed approach is simulated in SUMO [Behrisch et al., 2011]. SUMO can simulate up to 1,000,000 vehicles, and mobility can be created for different traffic scenarios

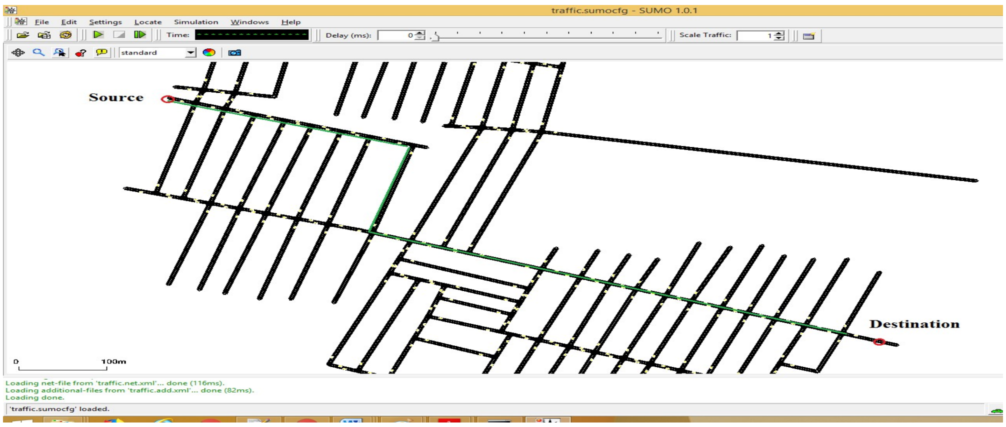

Fig. 12. Route for the Green Corridor

In the proposed approach, the real map of a locality of Bangalore (https://www.openstreetmap.org/export#map=16/13.1777/77.4129) is imported in SUMO, which is shown in Fig. 12. The route from the source to the destination is highlighted in the green line. In SUMO, each vehicle is uniquely identified using a vehicle Id. This unique code of the vehicle is used as the RFID tag's Id that identifies the vehicle at the Traffic Junction. In SUMO, different types of detectors are also available. For the detection of the vehicle "e1Detector" type detector is used as an RFID reader. This detector is installed at every traffic junction between the source and destination of the route. Under the normal scenario, emergency vehicles may have to wait at traffic junctions for green signal or due to traffic jam as marked in red color in Fig. 13.

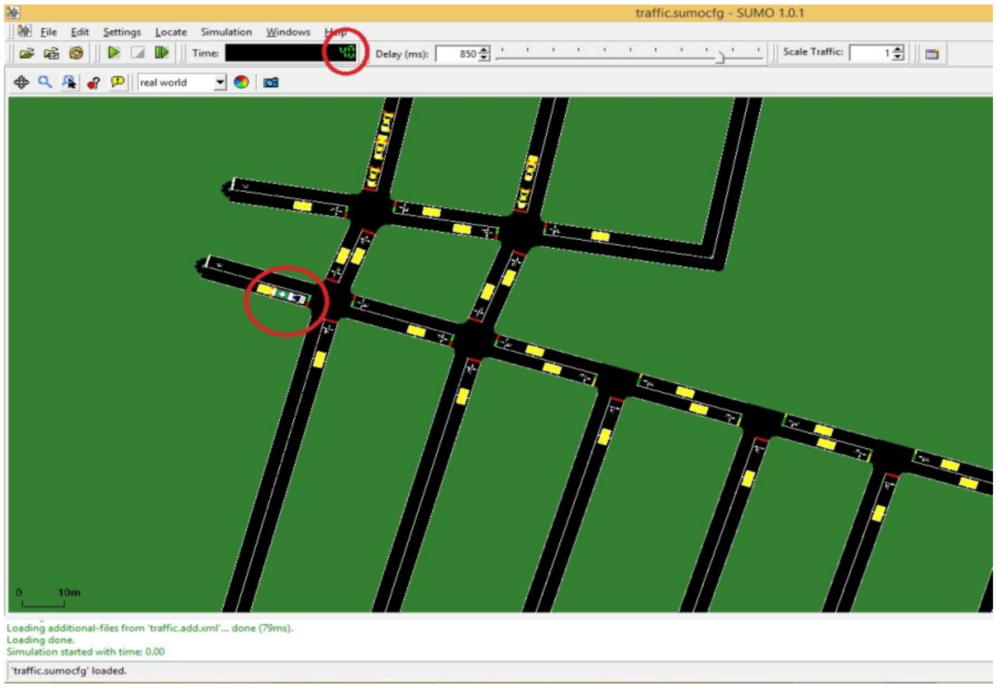

Fig. 13. Ambulance stuck in traffic jam (casual scenario)

If an emergency vehicle has to wait for a green traffic signal, it may lead to loss of human life. Therefore, an emergency vehicle must have a higher priority than other vehicles so that it can reach the destination without any delay. The emergency vehicle is distinguished from the normal vehicle using a type field from "normal" to "emergency". Twenty-three RFID readers are installed at different traffic junctions. The vehicle and route related data are stored in “net.xml” and “rou.xml” configuration files respectively. A separate python script is written for the execution of the proposed approach. This python script uses the sumo configuration file for changing the signal.The maximum speed of the vehicle is fixed at 80 km/h by changing the value of "maxspeed" parameter specified in “rou.xml” to 80. Different types of scenarios can be generated by changing the "maxspeed" parameter. Each traffic junction is installed with an “e1Detector”, which behaves as an RFID reader. The simulation is carried on two different scenarios. In the first scenario, the simulation is performed without using the proposed approach, and for the second scenario, the simulation is performed using the proposed approach by keeping all other parameters same for both scenario. When the traffic scenario is simulated without the proposed approach, at 40th time unit, it is found that the ambulance is stuck at a traffic junction as shown in the figure in 13. For the scenario in which the proposed approach is applied, the ambulance is able to cross the traffic junction at simulation timestamp of 40, which is shown in Fig. 14.

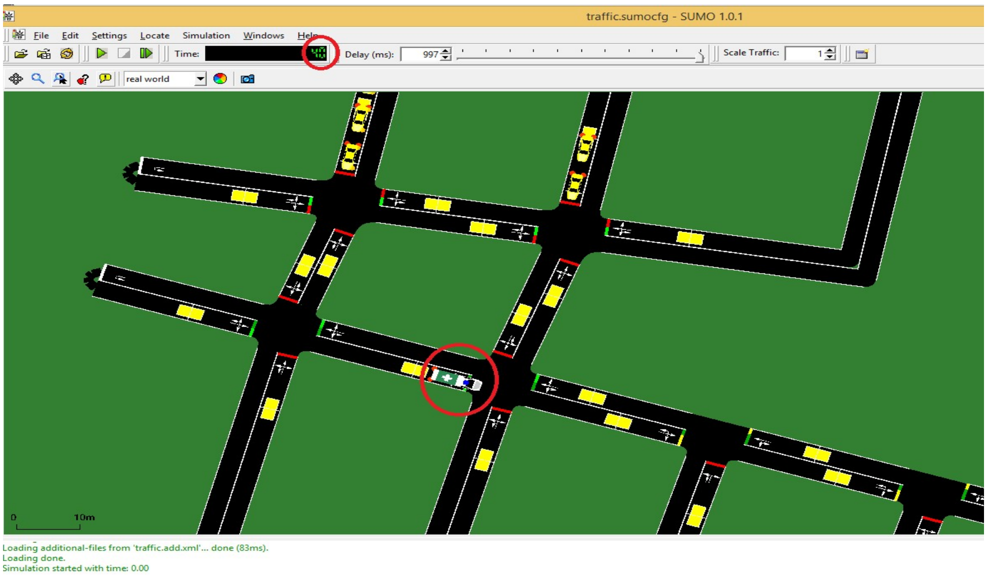

Fig. 14. Green single at traffic light for ambulance

In the simulation with or without the proposed algorithm, the total time taken by ambulance to complete the journey is 134 and 366 respectively as shown in Fig. 15 and 16 respectively. Simulation results establish that with the deployment of the proposed algorithm, an emergency vehicle requires less than 1/3 of the travel time of the normal vehicle. This verifies the robustness of the proposed system. Simulations are further carried out by changing all the parameter. The details of the simulation result are shown in table 2.

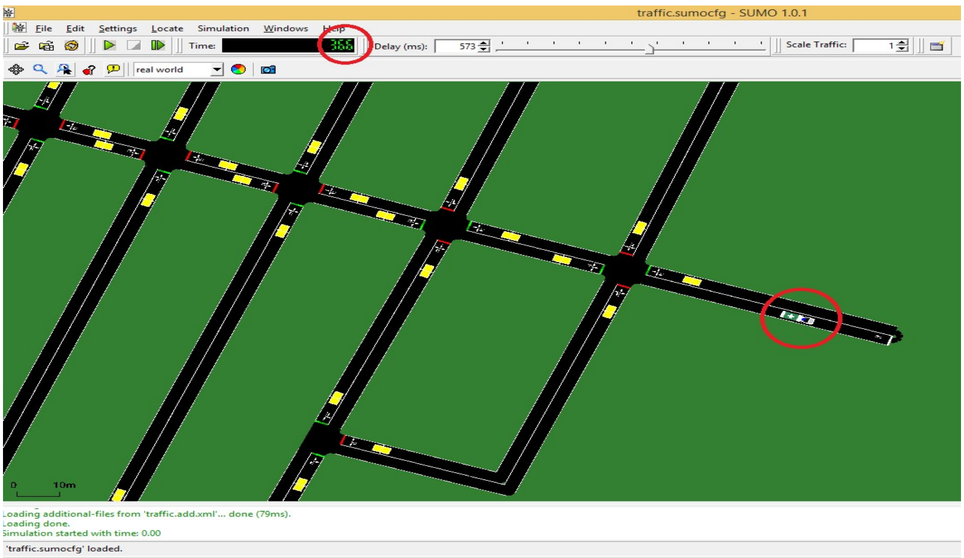

Fig. 15. Simulation completion without proposed algorithm

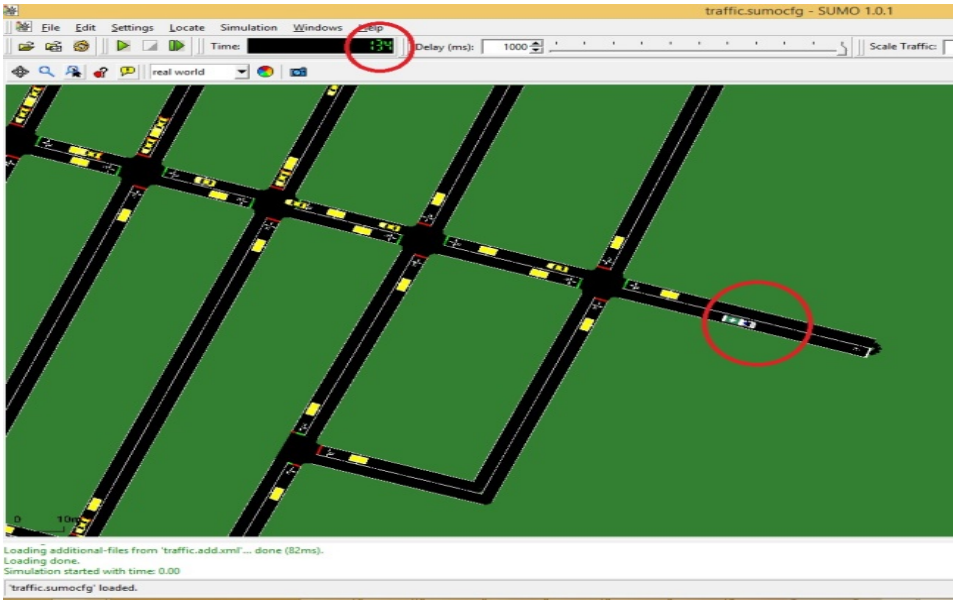

Fig. 16. Simulation completion with proposed algorithm

Table 2: Travel comparison of normal vehicle and emergency vehicle

Simulation serial number	Proposed approach applied?	Total number of traffic junction	Maximum Speed of vehicle	Time stamp of vehicle at 1st traffic junction	End time of Simulation	Total travel time	Time saved (%)
1	No	23	60	34	366	332	332.00
2	Yes	23	60	34	134	100	
3	No	6	20	32	184	152	286.79
4	Yes	6	20	32	85	53	
5	No	20	50	54	325	271	255.66
6	Yes	20	30	54	160	106	
7	No	21	30	60	320	260	166.66
8	Yes	21	50	06	162	156	
9	No	19	30	74	320	246	232.07
10	Yes	19	30	74	180	106	

As can be observed from the results listed in table 2, the average reduction in travel time of five different simulation for an emergency vehicle from source to destination is 254.6%, which is substantial. This is illustrated in figure 17. Further, movement of normal traffic is least disturbed when the proposed approach is applied.

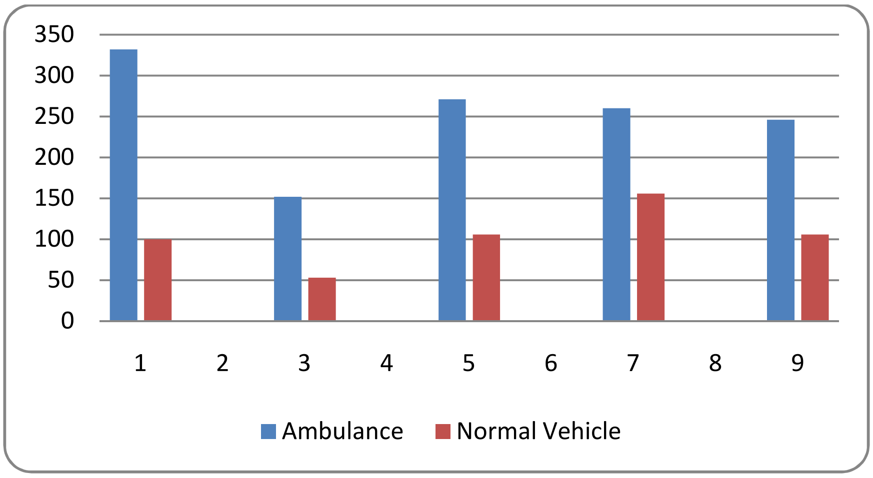

Fig.17.Comparison graph (proposed approach- ambulance vs. normal vehicle)

V. Hardware Implementation

The simulation results indicate that an emergency vehicle takes 2.5 times lesser time to reach from source to destination than a normal vehicle with the proposed approach. These results seem acceptable, given that it gives a similar satisfactory performance in a real-life scenario. To justify this, a hardware implementation has been done in a laboratory set up. An RFID reader is installed at two traffic junctions adjacent to each other. The two traffic junctions are created at a distance of one meter apart. A small toy car is fitted with the RFID tag to behave like an emergency vehicle. A low frequency (125 KHz) passive RFID tag is used for this purpose. Arduino (ATmega [X]) is used as a microcontroller. This microcontroller consists of 14 pins digital input/output which is capable to handle traffic light and RFID tag and receiver for our experiment. The RFID reader is connected to Arduino. Two multi-colored LEDs are used as traffic lights, which are controlled by the microcontroller. Initially, the first traffic signal shows green signal and reads the RFID of the passing vehicles. An ambulance fitted with RFID tag is passed slowly between two traffic junctions for experimental purpose. When the ambulance passes through the traffic junction, the RFID reader detects the vehicle and changes its green signal to red. It now sends a message to the next RFID reader and resumes the normal traffic signal operation. On receiving the message, the second RFID reader set its signal to green. When the ambulance passes through the second signal, the signal turns red to resume the normal flow of another vehicle. Multiple experiments are done by varying the distance and speed of the vehicle between the two RFID readers. Each time system behaves in the expected manner allowing the passage of the emergency vehicle through the green corridor. Fig. 18-20 shows the snapshots of the performed experiment.

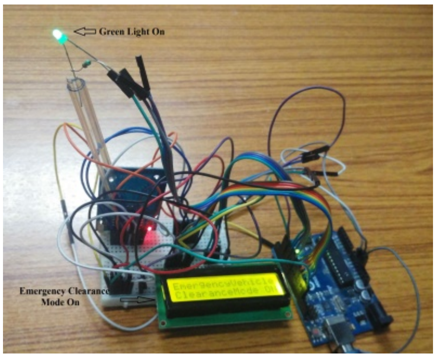

Fig. 18. Traffic junction movement RFID reader

Fig. 19. Emergency vehicle fitted with RFID

The green signal at the traffic junction (Fig. 18) is an indication for the RFID fitted emergency vehicle (Fig. 19) to pass through the traffic junction. When an emergency vehicle has crossed the traffic junction, the signal changes to normal allowing resumption of normal traffic as shown in figure 20.

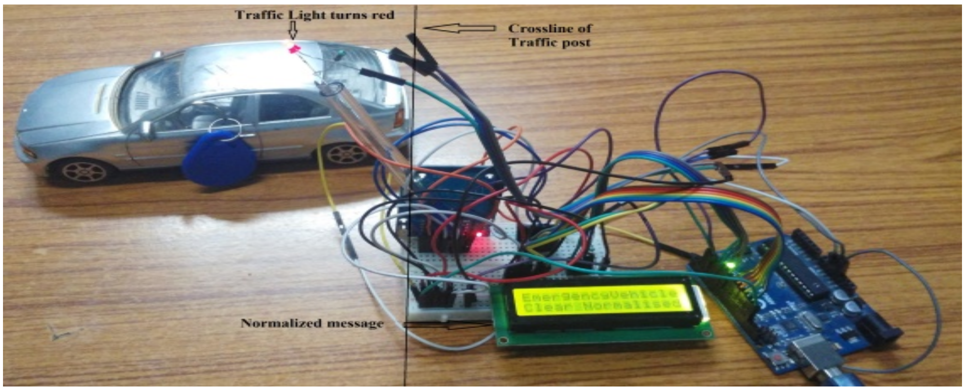

Fig. 20. Green Corridor movement

VI. Conclusion

Traffic jam is becoming a common problem in our daily life. In severe conditions, this may result in huge loss including that of human life and property. A smart traffic management system is the need of an hour to address the problem of traffic management. This research proposes an approach that provides clearance of an emergency vehicle in a cost-effective manner by creating an on-demand Green Corridor, causing the least disruption to normal traffic flow. The Green Corridor allows an emergency vehicle to travel from source to destination without any traffic congestion. The proposed approach has been tested through the detection of RFID tags at the traffic junction, simulation of vehicle movement in the Green Corridor and the hardware implementation in a laboratory-based environment. The average reduction in travel time for five different simulations for an emergency vehicle from source to destination is 254.6%, which is substantial.

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