An Automated Toll Gate System using VANET

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***Abstract*—Safe and optimum time of traveling is one of the major concern for all vehicle users. Due to technological advancements, the number of vehicles manufactured per year is increasing day by day. Also to save time during the transportation number of users using vehicles are also increasing day by day. While moving on the national highway, vehicles have to face toll gate system. Since the toll gate system is operated manually and the number of vehicles is increasing day by day, so average waiting time per vehicle and Total service time (TST) at the toll increases. In this paper, an automated toll system is proposed through vehicular ad-hoc network (VANET) to reduce average waiting time per vehicle and TST. The proposed routing protocol is compared in terms of generic network parameters like End-to-End delay, and TST with the existing VANET routing protocols i.e. Geographic Source Routing (GSR) and Anchor based Street Traffic Aware Routing (A-STAR).**

***Index Terms*—VANET, TST, automated toll system**

I. Introduction

Any frequently used public resource i.e. national highway, roads, traffic light system, cinema hall, public park etc. requires maintenance. The maintenance of these resources are costly. Highways and roads are not the exception. Due to the advancement of technology, number of vehicles manufactured per year is increasing day by day. Fig. 1. shows the number of vehicles manufactured per year in India [1]. Increase in number of vehicles puts overhead on increase in the maintenance cost of national highways and roads. Government collects the construction, maintenance, and operating costs for the national highways and roads by two methods [2]. The first method is the indirect method in which the construction and maintenance cost are collected by paying tax for fuel or by the budget allocation of the national income. The pitfalls of this method is that some people having no vehicles and frequently not using the national highways have also to pay extra money as the tax. The second method for obtaining the construction and maintenance cost is the direct method. In this method, the required construction and maintenance cost are directly collected from the drivers using the vehicles passing through that national highway or roads. Example of this direct method is the toll gate system.

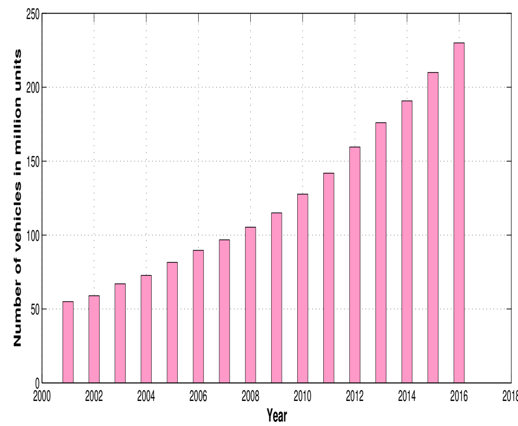

Fig. 1. Number of vehicles manufactured per year in India

In the traditional process, tax is collected from the owner of the vehicles or from the drivers. The conventional way of collecting the tax is to stop the vehicles at the toll gate stations. Based on the type of vehicles i.e, heavy or light vehicle, required amount is paid to the toll collector present in the toll booth. Collection of payment receipt for future use after the payment. After all this process, the toll gate is opened either mechanically or electronically for the drivers to pass through the toll system.

This traditional process of toll tax collection has several limitations. The first limitation of the toll tax collection is the delay occurred due to stopping of vehicles and collection of tax. According to the study of high traffic highways, the average delay at the toll gate is around 10 minutes and this delay costs the Indian economy Rs 27,000 crore every year [3]. The second limitation is the loss of fuels due to the delay and slow motion of the vehicles. The survey shows that the fuel consumption cost is around Rs 60,000 crore per year due to delay and slow motion of the vehicles at the toll station [3]. Everyday millions of vehicles are moving on the national highway and crossing the toll gate. For every vehicle a paper receipt is provided which also incurs huge loss. Also gathering of large number of moving vehicles at the toll gate during peak time also affect the environment at that location to some extent.

Above limitations of traditional toll gate system demands to develop the automatic toll gate system. This paper proposed an automated toll gate system using Vehicular Ad-hoc Network (VANET). VANET is popularly known as network on wheels in which vehicles act as the sender, receiver, router, and forwarder [4], [5]. Fig. 2. shows the different components of the modern vehicles which makes the vehicle smart and intelligent carrier [6].

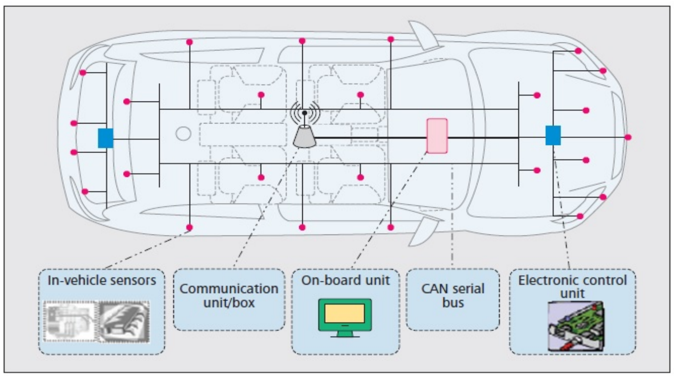

Fig. 2. Smart and intelligent vehicle

The two components of VANETs are vehicles - the mobile nodes, Road Side Unit (RSU) - the static nodes. Based on these two components, communication in VANET is classified into two categories.

- Vehicle to vehicle (V2V)
- Vehicle to infrastructure (V2I) or Infrastructure to Vehicle (I2V)

Fig. 3 shows the two types of communication in VANET.

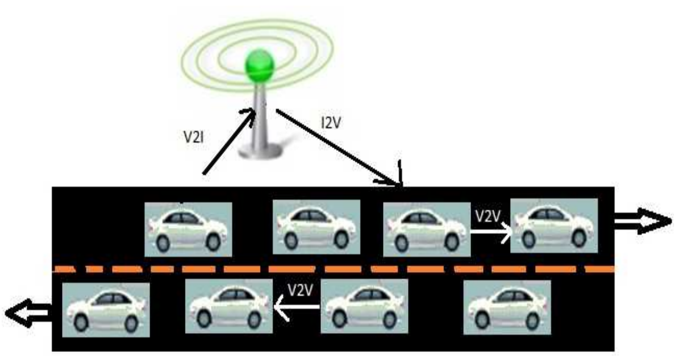

Fig. 3. Types of communication

The communication may be between vehicle to vehicle or between vehicle to infrastructure, but for the transmission of information from the source node to destination node, an efficient routing protocol is required. In VANET, different types of routing protocols are used. Fig. 4 represents different types of routing protocols used in VANET.

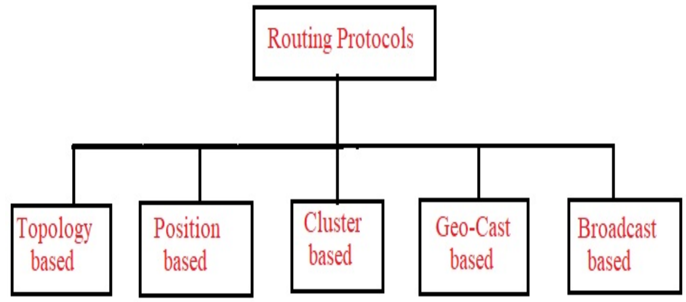

Fig. 4. Types of Routing Protocols

The measure contribution of this paper is as follows.

- Transmission of vehicle information from the near by RSU to Toll Station using minimum end to end delay.
- Collection of vehicle information using toll database system by using MongoDb and performing required operation on the database using node-red.
- If the vehicle information is not stored on the toll database system, then during manual collection of tax, information can be stored in the database. this will avoid the future manual collection of tax.
- Total service time is computed using M/M/1 queuing model.

The rest of the paper is organized as follows. Section II describes the motivation for this paper. Literature survey is presented in Section III. Section IV discusses proposed method. Section V presents simulation set up and simulation result. Finally conclusion and future scope is mentioned in Section VI.

II. Motivation

The motivation for our work is as follows.

(i) The average delay at a toll gate system is around 10 minutes. According to the study of high traffic highways, this delay costs the Indian economy around Rs 27,000 crore every year. Due to the slow motion of the vehicle, the fuel consumption cost is around Rs 60,000 crore per year [3].

(ii) Manual collection of toll tax at the toll station also leads to discrepancy in the money collection figure. Until march 2014, under Right to information (RTI), total toll tax collected figure were Rs 885 crore. But the toll collecting agency showed a figure around Rs 601 crore. The difference of Rs 284 crore is a huge discrepancy. [7]

(iii) Millions of vehicle are crossing the toll gate everyday. Providing hard copy of receipt through paper to driver is also very costly as these receipt is useful during the 24 hours of journey.

(iv) Also automated toll gate system through VANET also does not requires separate special communication unit for vehicle. Presence of on board unit is helpful to develop an efficient automated toll gate system.

Thus, availability of communication unit in VANET and to avoid the limitations of manual toll gate system like delay, fuel consumption cost, wastage of paper and the paper cost, and to avoid traffic during peak period of toll collection provide motivation for the development of automated toll gate system using VANET.

III. Literature Survey

Many researchers are working for the optimization of cost, minimization of delay, and improvement in the total service time for the tax collection at the toll gate system. For the smooth collection of toll tax, chung et al. proposed several safety operational guidelines for the toll system which may be manual toll system or electronic based toll system [8]. To avoid the limitations of manual toll tax collection like wastage of fuel, long vehicular queuing time, high accidental risk, and pollution of region near toll collection due to accumulation of large number of vehicles, Popoola et al. proposed a cloud based intelligent toll system for smart cities [9]. In the smart and connected communities Oluwafunso et al. proposed a framework for electronic toll collection. The main component of the proposed architecture consists of wireless sensor node, cloud platform, and cellular technology [10]. Due to monopoly of private agency collecting the toll tax, discrepancy in the amount of toll collection per year, S.K.Nagothu proposed an automated toll system using the technique GPS and GPRS [11]. Chang et al. proposed toll collection through intelligent transport systems (ITS) in which toll tax collection was shifted from ”time based charge” to ”mileage based charge” [12]. To reduce traffic congestion, to decrease the wastage of fuel Tan et al. proposed a GPS based highway toll gate system [13]. The components of the proposed system are GPS module, LCD module, wi-fi router, speaker, and wi-fi adapter to perform specific task in toll tax collection system. To develop a reliable electronic toll collection (ETC) system at optimized cost, Chattoraj et al. proposed a low cost ETC system [14].Illegal toll collection, failure of toll system, and insecure connection with the toll system was addressed by Gupta et al. [15]. Inserra et al. proposed planar antenna array for the toll gate system which is based on radio frequency identification (RFID) technique [16]. To reduce pollution and to decrease the traffic congestion in urban areas, Cedo et al. proposed a privacy preserving dynamic pricing toll gate system [17].

IV. Proposed method

The proposed method consists of different phases. Various phases of the toll tax collection method are as follows.

(i) Data collection phase
(ii) Routing phase
(iii) Data extraction phase
(iv) Data base operation phase
(v) Acknowledgement delivery phase

A. Assumptions

For the fast and efficient system of toll tax collection, some assumptions are considered. These are as follows.

A1 All the Road Side Units(RSUs) have fixed infrastructure i.e. RSUs are static in nature.
A2 RSU present before the 1km from the toll base station initiates the data collection phase.
A3 Processing unit, storage capacity, the transmission, and reception range for RSUs are more than that of OBUs of the vehicles.
A4 The communication between the nodes is the multihop communication.
A5 Symmetric link is established between the nodes for the connectivity between the nodes.
A6 GPS and maps are used for the identification of the vehicles.

B. Data collection phase

Road side unit (RSU) which is present just before 1km from the toll base station initiates the data collection phase. RSU consists of camera module which can capture the image of the vehicle along with the vehicle number.

C. Routing phase

In the routing phase, an effective route is determined from the RSU to the toll base station. For the one way movement of the vehicle, around four toll station are present in the toll system. This means at a time four vehicles information can be processed simultaneously. So routing phase, determines the effective route from the RSU to any one of the toll station. To determine the effective route for the transmission of the camera module information, two factors are considered. First factor is the shortest distance from the RSU to any toll station. The second factor for the determination of effective routing path is the density of vehicles. The path having more number of vehicles is suitable for the transmission of the camera module information. Thus, effective routing is computed as follows.

$$Route_{value} = w_1 \times SPATH + w_2 \times Density \qquad (1)$$

The Route $_{effective}$ is computed from RSU to the four toll station. The maximum value of effective route is selected as the path for the transmission of camera module information. All the four toll stations are interconnected so that the information is shared between all the four stations. This helps in the transmission of vehicle in that path which have minimum density of vehicles among the four toll stations.

D. Data extraction phase

At the toll station, after getting the image from the camera module through effective route, the vehicle number is extracted. The extracted vehicle number in the form of text acts as the input for the database from which the details information of the vehicles can be retrieved.

E. Database operation phase

The vehicle number extracted from the database act as the input to the database. If in the database the vehicle information is present, then from that information the types of vehicle is determined i.e. whether the vehicle is heavy vehicle or light vehicle. This is required because based on the type of vehicle, different tax will be collected. For every vehicle, the bank account information is associated with the database, automatic deduction of the required amount from the bank account account has to be done. If the vehicle information will not be able to access, then the toll tax will be collected manually. At the same time, the vehicle information should be inserted in the database, for the future automatic toll collection.

F. Acknowledgment delivery phase

After the successful automatic toll tax collection, the information about the deduction of money from the account should be sent as e-mail to the corresponding owner mail-id. This will act as the receipt of toll collection which will save the wastage of huge amount of paper.

The pseudo code for the path selection process is described in the algorithm 1.

Definition of performance metric

The proposed work considers the evaluation of end-to-end delay and total service time.

- **End-to-end delay (E2E delay)**: Total time taken for the transmission of vehicle image taken by the camera module from RSU to toll station.
- **Total service time (TST)**: TST is the sum of message extraction time, data searching time in the database, automatic toll collection time.

TST normally consists of queuing time(message extraction time) and service time (sum of data searching and toll collection time). To compute TST, M/M/1 queueing model is considered [18].

V. Simulation Result and discussion

For the routing phase, simulation is carried out by SUMO and OMNet++. For the database operation mongoDB along with node-red is considered.

A. Simulation set up parameters

Simulation set up is presented in TABLE 1.

TABLE I
Simulation Network Set up Parameters

Parameters	Values
Simulation area	$2000m \times 2000m$
Communication range	250 m
Size of packet	512 bytes
Speed of the vehicles	30-50 km/hr
Number of vehicles	5-25
Number of Toll station	3

The communication between the nodes (vehicles or RSU) is multi hop and the communication range is 250m. The simulation is performed in an area of $2000m \times 2000m$. The speed of the vehicle is within the range of 30 to 50 km/hr. The simulation is performed over the varying number of vehicles from 5 vehicles to 25 vehicles. As per the VANET standard, the size of packet is 512 bytes. In the simulation 3 toll stations are considered means at a time maximum 3 vehicles can pass through the toll system.

Algorithm 1 Automatic Toll Tax Collection

Input: Vehicle information in the database, RSU with camera module.
Output: Fast efficient way of toll tax collection with acknowledgment.
Capture the image of the vehicle from the camera module available in the RSU.
for RSU to $Toll_{Station}$ **do**
  if $intermediate_{hop} \neq Toll_{Station}$ **then**
    for each path connected to the current hop $hop_{Current}$ **do**
      $hop_{Current}$ calculates shortest path to each toll station;
      $hop_{Current}$ calculates the density of vehicles to each toll station;
      $hop_{current}$ transmits the computed information to the RSU.
    end for
  end if
  RSU calculates $Route_{value}$ to each toll-station by: w1 $\times$ SPATH + w2 $\times$ Density
end for
Path having maximum $Route_{value}$ is considered as the effective route;
Transmit the image information from the RSU to the toll station on the effective route;
Extract the vehicle number from the image at the toll station.
Provide vehicle number as the input to the database.
Search the vehicle information from the database.
if Vehicle information is present in the database **then**
  Determine the type of vehicle;
  Deduct the required amount of toll tax from the saved account automatically.
  Send the acknowledgment to the registered email regarding the transaction of money.
else
  Manually Collect the toll tax.
  Insert the information of the vehicle in the database for future automatic toll tax collection.
  An email will be sent consisting of information regarding the addition of vehicle information at the toll system.
end if
STOP

B. Simulation Result

The E2E delay and the TST of the proposed routing is compared with two existing VANET routing protocol i.e. Geographic Source Routing (GSR) [19] and Anchor based Street Traffic Aware Routing (A-STAR) [20]. The network traffic and the movement of vehicles are generated with the simulator SUMO. Fig. 5 shows the part of the toll system implemented using SUMO. The network traffic scenario generated from

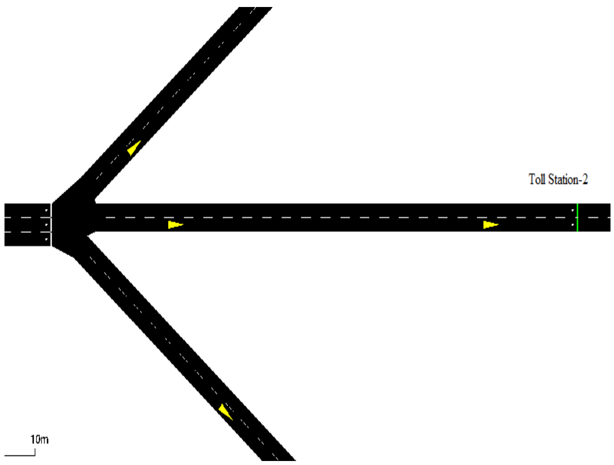

Fig. 5. Part of Toll System using SUMO

SUMO is integrated in OMNET++ to compare the network performance in terms of parameters E2E delay and TST of the proposed routing protocol with GSR and A-STAR. Fig. 6 shows the E2E delay comparison.

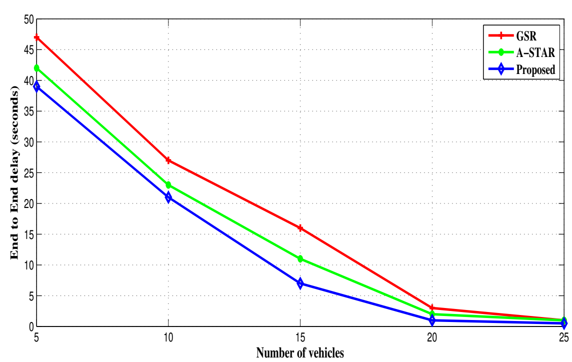

Fig. 6. E2E delay

Fig. 7 shows the Total Service Time comparison of the proposed routing protocol with GSR and A-STAR. For the database operation, node-red and mongoDB database is used. Through node-red the vehicle number is provided as the input. If the vehicle number is not present in the database it will display a message to enter the vehicle information. If the vehicle information is present in the database, it will display the details of the vehicle stored in the database. Fig. 8 shows the node-red wiring diagram with mongoDB.

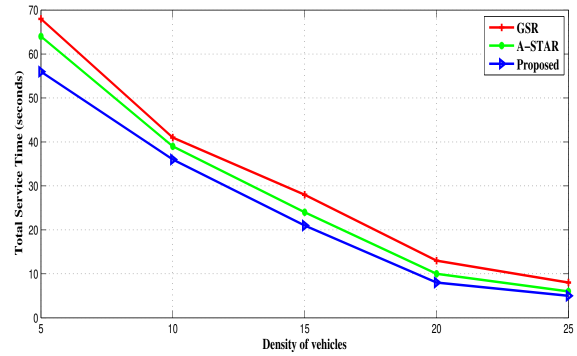

Fig. 7. Total Service Time

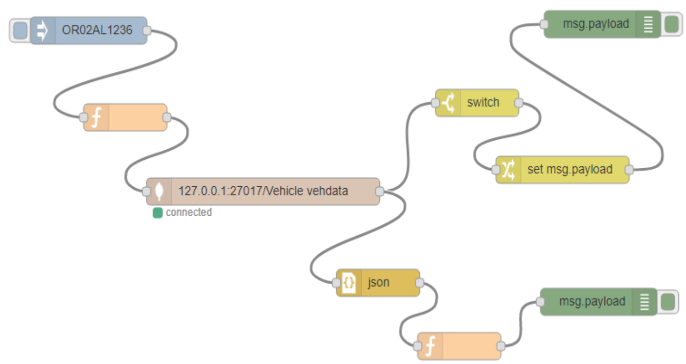

Fig. 8. Node-red wiring diagram with mongoDB

By providing different vehicle number as the input to the node-red, based on the search, the serial monitor display different output. Fig. 9.a shows the serial monitor output for the successful search. Fig. 9.b shows the serial monitor output for the unsuccessful search. Fig. 9.c shows new vehicle information addition message after the unsuccessful search.

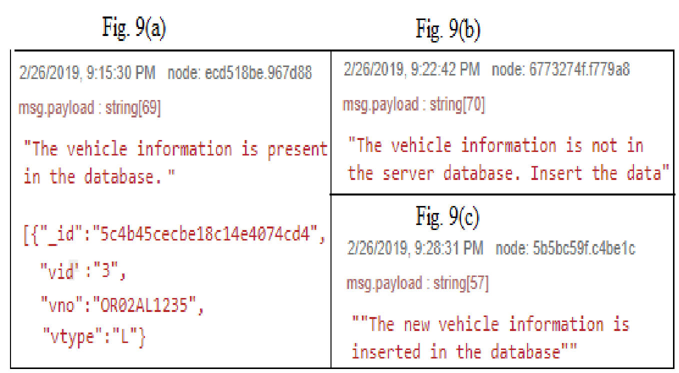

Fig. 9. Output of serial monitor of node-red

The part of the mongoDB database information is shown in Fig. 10. The database is named as Vehicle and the corresponding collection name is termed as vehdata. The part of the information present in the database are vehicle-id (vid), vehicle-no (vno), vehicle-type (vtype). _id is the implicit attribute generated by the mongoDB.

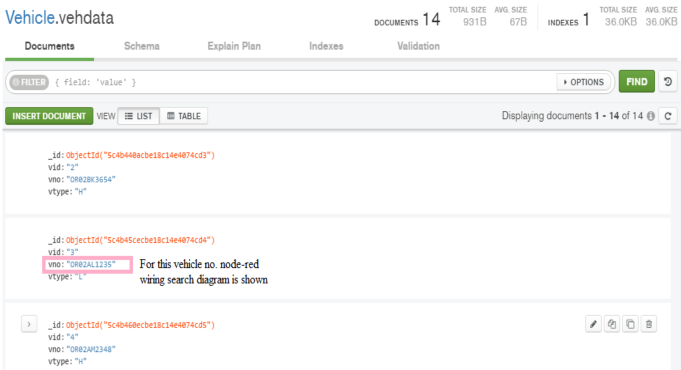

Fig. 10. Part of the content of mongoDB

VI. Conclusion & Future Scope

In this paper, an automated toll tax collection is proposed using an routing protocol with the help of RSU and vehicles present between the RSU and toll station. This is one of the optimum cost technique and also reduces the delay as compared to manual toll tax collection. The proposed routing is compared with the existing VANET protocol i.e. GSR and A-STAR in terms of E2E delay and Total Service Time (TST). In future, a real test on VANET platform could be performed by using the transceiver module in the vehicle. Also to the routing mechanism and also in the transaction some security mechanism could be added.

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