# Blockchain-based Booth-less Tolling System using GPS and Image Processing

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***Abstract*—India as a country is aggressively investing in building better roads and highways, but due to the costly nature of these projects, they are done in the form of a Public Private Partnership. This makes the efficient collection of toll tax highly important to incentivize further development of infrastructure. Currently, the FASTag system of tolling is employed in India which is resulting in unorganized and inaccurate revenue collection, physical problems like tags getting damaged, traffic congestion and reduced fuel efficiency. To solve these problems, a blockchain-based virtual tolling system using GPS and Image processing is proposed. In this paper, appropriate hardware and software designs were involved to develop a GPS-based highway toll collection system further complemented with image processing to get the number plate data. A blockchain-based technology to implement a decentralized, secure toll collection mechanism that uses blockchain smart contracts to store data.**

***Index Terms*—blockchain, ethereum, smart contracts, image processing, tolling, GPS**

## I. Introduction

A developing country like India with a growing economy needs to invest heavily in creating quality infrastructure in the form of roads and highways. Efficient toll collection is very important to ensure this. As of 2022, the FASTag toll collection system accounts for 97% of the nearly Rs 50,855 crore in total toll revenue [1]; the remaining 3% pay higher than usual toll rates due to not using FASTags. The FASTag system has many flaws though, some of which are double deduction, tag damages because of weathering, technical glitches, account blacklisting, consistent traffic congestion and unorganized and inaccurate revenue collection because of high intrusion of the human component in the toll collection process [2]. Strict enforcement of the permissible delay of 10 seconds [3] during the tolling process could lead to heavy financial losses. These problems can be resolved using various prevalent technologies like GPS (Global Positioning System), GNSS (Global Navigation Satellite System), and ANPR (Automatic number-plate recognition) systems which could be much more reliable as opposed to RFID systems employed in FASTag. Furthermore, blockchain-based smart contracts could decentralize the toll collection process and make it more secure.

The solution proposed in this paper is in the form of an OBU (On Board Unit) to be integrated into the number plates of vehicles that will enable the GPS and GNSS systems and an ANPR system can be integrated into the cameras that are installed at the entry and exit points of highways, which are further considered as a geofence for the GNSS system, as a means of double verification. The primary aim of the proposed solution is to eliminate a single point of failure. Also, to keep the data secure, decentralized and reliable, blockchain technology is utilized in the form of Ethereum smart contracts.

## II. Literature Review

The nature of the problem required a thorough literature review of the various papers that were available in this area, many of which provided us with great insights that helped us understand the present gaps and encouraged us to further innovate to rectify those gaps.

Since FASTag is based on RFID technology. We found some resources that went into implementing or improving the system. [4] designed a system using EM-18 RFID Reader for scanning the RFID Tag, cameras were placed in case the car did not have a tag or the tag had insufficient balance. The system was made such that the vehicle had to stop momentarily in order for the RFID scanning to work properly. [5] presented a solution with the MFRC522-based RFID reader which used the SPI interface for communication with the computing device which is significantly faster than EM-18 which communicated using UART. [6] proposed a system designed on nRF9E5 RF System on Chip (SoC) powered by an 8051 microcontroller for reading the RFID tags. The authors proposed adding a redundant RFID reader to improve the reliability of the system.

After studying the drawbacks of the RFID systems, we tried to find solutions that could retrieve the number plate automatically with as little delay as possible. [7] proposed an ANPR system based on Barcode and Laser technology to retrieve vehicle information. The vehicle had to stop momentarily for scanning the barcode stuck on the windscreen of the car. Even though the system is very cost-effective, barcodes can be easily damaged and the scanning has to be done sequentially as opposed to RFID which can scan multiple tags simultaneously. [8] proposed a computer vision system using the OpenCV library running on Embedded Linux to detect cars by using grey scaling, object detection and Kalman filter for background subtraction. The main aim of the model was to classify the type of vehicle (e.g., heavy or light) which is crucial for appropriate toll pricing, however it lacked any mechanism for detecting the nameplate number of the vehicle. This problem was solved by [9] which used Canny Edge detection and Hough transformation followed by Optical Character Recognition to detect the vehicle number. [10] presented us with a UI system that worked with License Plate Recognition software to create an appropriate RFID-less tolling system. edas

Considering the different techniques used previously, it was necessary to figure out which technique should be used in order to replace the existing FASTag technology. Using the PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation) model for Multiple-criteria decision-making, fuzzy logic and with the help of domain experts [11] was able to determine the ranking based on the effectiveness of multiple technologies that could be used in tolling systems. Of the 14 technologies considered, RFIDs equivalent to FASTags, ANPR Systems and GNSS were ranked 7, 6 and 4 respectively. This conclusion further helped the initial proposal as toll booths already had cameras installed and all that was needed was to create an appropriate onboard unit (OBU) for transmitting GPS data. Therefore, our proposed system has two data sources: one being the GPS data transmitted by the OBU and the Nameplate number and other vehicle details captured by the ANPR systems.

With the data sources taken care of, we dived into the problems that took place in the backend. A centralised storage server is prone to attacks that could lead to tampering and corruption of data. A decentralized system, however, is much more robust. [12] provided a mechanism for secured storage of toll booth transactions on a government-owned private blockchain which used elliptic curve cryptography (ECC) to encrypt the user data and would remain that way unless a court order was issued for investigation. They also tested and verified the robustness of the system with multiple attacks such as reentrancy, front-running and gas limit DoS. We were partly inspired by [13] which presented a decentralized electronic toll collection (ETC) system using OBUs and Road Side Units that would collect the vehicle information which would then be put in the blockchain. This data can then be processed by the relevant authorities to generate the billing amount for the users.

Analysing all the previous work, we propose a decentralized architecture that consists of an onboard GPS module installed on the vehicle and an ANPR system installed on the RSU from where the data is transferred to a government-owned private Ethereum blockchain and IPFS network.

## III. Methodology

### A. Hardware Description

The hardware unit consists of an ESP8266 Node MCU which is a low-cost Wi-Fi microchip, with built-in TCP/IP networking software, along with a Neo 6M GPS Module. The microcontroller is programmed to transmit the data over a Wi-Fi connection. The GPS module interacts with the Node MCU via UART at 9600 baud rate and transmits the GPS coordinates of the OBU via Wi-Fi to a GPS data processing server. The circuit diagram is given in Fig. 1

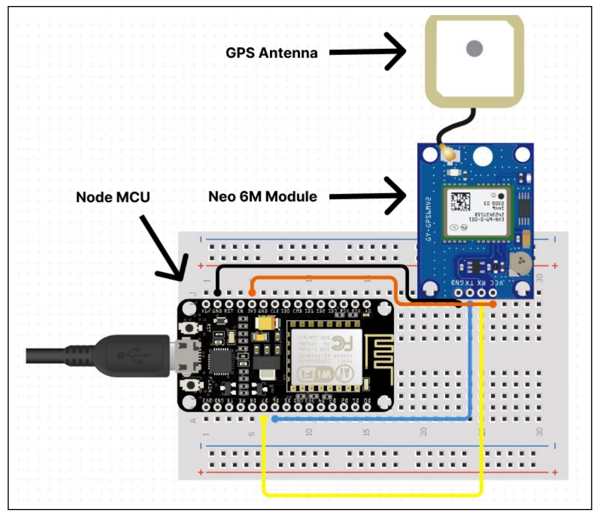


Fig. 1. Circuit Diagram for GPS Data Transmission Unit with Node MCU and Neo 6M GPS module

### B. Algorithm and Process Flow Model

A 2-stage process is designed in this paper. The stages are as follows:

**Data Collection and Validation**
The GPS coordinates of the car are streamed to the server via the GPS module present on the OBU. A server then checks if the vehicle has reached a specific toll location. If yes, then the GPS details are sent to the respective RSU for completing a data block.

Simultaneously, the camera on the RSU captures the nameplate numbers and marks the start and end times for when a nameplate number was visible, it stores the video stream to a decentralized storage private IPFS network, whereas the timestamps, nameplate numbers and the video stream hash are added to the data block.

An RSU maintains a hashtable as shown in Table. I to store the ANPR data as well as GPS data. It enters whichever data is received first and creates an entry in the hashtable, with the nameplate number as the key. When the remaining data is received, the hashtable is simply updated to complete a data block.

TABLE I
DATA BLOCK PARAMETERS

| Nameplate | RSU ID | Latitude | Longitude |
|---|---|---|---|
| Car visible from | Car visible till | Video Address | Entry or Exit |

To maximize the level of decentralization and minimize the risk of data tampering, the data is temporarily stored in the RSUs till the data blocks can be added to the blockchain.

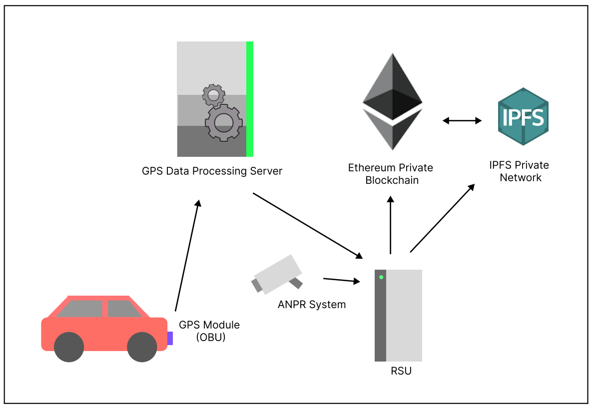


Fig. 2. Block diagram of proposed model showing the flow of data

**Data Freezing**

An entry is considered completed if it contains the GPS data as well as the image data. Updation of the data is allowed only for a specific timeframe after which it is stored in the blockchain, maintaining incompleteness. This way we restrict the chance of data tampering when the entry is still on the RSU. Once the data is completed or validation is no longer possible, the data blocks are stored in the smart contract. Fig. 2 describes the proposed decentralized model.

**Data Recoverability**

In an ideal system, the data blocks associated with a number plate will be in pairs (there will be an exit data block for every entry data block) in a given permissible interval. However, if a situation arises where one of the blocks doesn't have a pair, a correctional data block could be inserted that would contain the details of the nearest entry or exit point respectively. Since we have 2 data sources as opposed to 1, we are significantly decreasing the chances of this anomaly from happening. Table. II compares the recoverabilty of data in case of a failure.

## IV. SIMULATION AND EXPERIMENTAL RESULTS

The software part of this study comprises of technologies mentioned below:
**Node.js:** Web Server that handles all the requests
**PlateRecognizer API:** To perform ANPR
**Ganache:** For creating a local ethereum testnet

TABLE II
DATA RECOVERABILITY

| Entry Data | Exit Data | Recoverability |
|---|---|---|
| Received from both ends | | No need |
| Received from any one end | | Partially recoverable |
| Not received from both ends | | Irrecoverable |
| **Recoverability with 1 data source** | | 66.67% |
| **Recoverability with 2 data sources** | | 85.71% |

**Kubo:** For creating private IPFS network

To better understand the functioning of the infrastructure developed, a web based simulator was designed to test and give a bird's eye view of the project. In Fig. 3, the functioning of the simulator can be observed. The car sprite transmits the gps data to the server. The data blocks and the status (whether or not the data is uploaded) are observed for each RSU on the left side of the page.

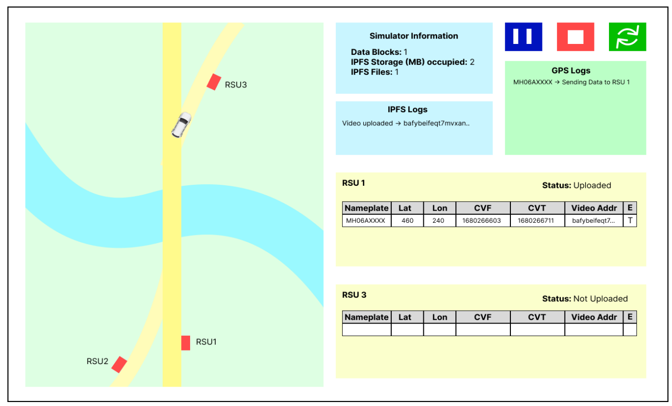


Fig. 3. Simulator output during an ongoing simulation

Furthermore to demonstrate the working of the GPS module, Fig. 4 shows the GPS coordinates being printed on the Serial Monitor which could be streamed to a server as mentioned above.

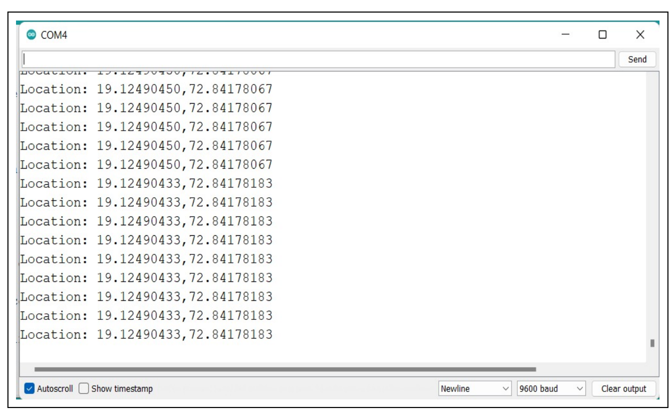


Fig. 4. Serial monitor output displaying location data

The ANPR API used in the simulator is based on the YOLO (You Only Look Once) model [14] and has a maximum reliable speed limit of 96 km/h with a camera recording at 12 eFPS (effective FPS) where eFPS is the ratio of frames per second (FPS) captured by the camera and Sample Rate of the ANPR software.

As of writing this paper, the ethereum mainnet is capable of processing **30** transactions per second. However with the emergence of Ethereum 2.0, it will be capable of handling **1,00,000** transactions per second due to its shift from PoW (Proof of Work) to PoS (Proof of Stake) consensus algorithm [15]. A private network is certainly expected to be faster and the processing speed is dependent on the number of nodes and type of hardware the blockchain is running on. Similar behaviour is expected from a private IPFS network. The simulator operates with a few seconds of latency because of a local setup, larger latencies could be expected when used in real life.

## V. Conclusion

A blockchain-based booth-less tolling system is developed and demonstrated in this study. The system is designed in a way to remove a single point of failure and make the data storage reliable and tamper-proof. This is achieved by using two sources of information, the onboard GPS unit and the ANPR software working in coordination with each other to obtain valid and reliable data. The results could be further improved by selecting an appropriate blockchain e.g., Hyperledger Fabric, a permissioned private blockchain platform that could handle large amount of transactions per second, or Polygon, a carbon neutral ethereum blockchain. An on-premise ANPR software deployed on the RSUs and designing efficient algorithms for merging the two data sources can greatly impact the performance. Furthermore, selecting and developing cost and energy-saving hardware for the GPS OBU would make it easy to realise our proposed system. As the efforts continue in the domain of image processing and decentralisation of software, the above study will benefit greatly and develop into a more reliable and trustworthy system.

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