A Framework for Electronic Toll Collection in Smart and Connected Communities

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***Abstract*—The number of vehicles plying the highways keeps growing at a steady pace, leading to high maintenance costs. Toll collection was introduced as a means of raising funds for road maintenance, but the traditional method is usually slow and is prone to cause vehicular traffic congestion on the highways. In this paper, a framework was proposed for Electronic Toll Collection (ETC) in smart and connected communities. The main components of the intelligent system architecture are the wireless sensor nodes, web and mobile applications, and a cloud platform. The Wireless Sensor Network (WSN) enables vehicle detection and classification, and establishes a communication link to the back-end of the system. The central database and the web server are hosted in the Cloud while a mobile application is used for electronic transactions, subscription renewal, notification of toll payments, and for tracking toll payment history. In addition, a web dash board is provided for efficient toll administration. The implementation of this system will improve the toll collection efficiency in terms of speed and flexibility. Overall, the contribution of this work extends the frontier of WSNs to the domain of Intelligent Transportation System (ITS).**

***Index Terms*— Electronic Toll Collection; Intelligent Transportation System; Wireless Sensor Network; Cloud Computing; Internet of Things.**

I. Introduction

As highways become more and more important in modern transportation networks, the inefficiencies of traditional toll collection systems tend to be unbearable for users because they often result in long vehicle queues and traffic congestion. ETC systems seek to address this problem by reducing the waiting time on the toll highways. Significant reduction in the delay period will minimize unproductive fuel consumption, air pollution, unnecessary road congestion, and increase road safety [1]. The ETC system was basically designed to ease traffic flow during toll collection, and it has become an important part of ITS [2].

In this era of rapid technology development, conventional systems are being replaced with automated systems. Automation minimizes human interference, ensures reduction in time and energy, and increases efficiency. The ITS era emerged with the revolution in computer, communication, and embedded system technologies [3]. ETC, as a part of ITS, has been extensively deployed to ameliorate the traffic delay, and it has drastically improved the efficiency of road operations [4, 5].

The use of roads is rapidly increasing as the number of vehicles plying them keeps growing, leading to high maintenance costs. Toll collection was introduced as a means of raising funds for road maintenance, but it is traditionally a slow process prone to cause vehicular traffic congestion. Several efforts have been focused towards making the toll collection process faster and more transparent [4-10]. The numerous advantages of the toll collection system make the whole effort worthwhile, a few of which include revenue generation for the maintenance, rehabilitation and reconstruction of roads, as well as road use demand management and control. Therefore, automating this process is an indispensable task able to bring great benefits, and will help to increase the standard of living, while indirectly contributing to the goal of making cities smarter.

In this paper, we propose an architecture for ETC in smart and connected communities. The main components of the smart system architecture are: the wireless sensor nodes; web and mobile applications; and a cloud platform. The Wireless Sensor Network (WSN) enables vehicle detection and classification, and establishes a communication link to the back-end of the system**.** The central database and the web server are hosted in the Cloud while a mobile application is used for electronic transactions, subscription renewal, notification of toll payments, and for tracking toll payment history. In addition, a web dash board is provided for efficient toll administration.

II. Related Work

In the literature, the use of Dedicated Short Range Communication (DSRC), which includes bar-code and Radio Frequency Identification (RFID), has proved to be effective; but it is usually affected by signal interference. In case of a barcode-based ETC, a sticker with an imprinted barcode is placed under the wind shield of the vehicle, and it is read by the laser barcode reader on the toll plaza as the vehicle passes through. This method has been extensively reported in the literature [2, 4, 10-18]. However, the technique has less accuracy under bad weather conditions (especially when it is foggy). Also, it is not reliable because

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any barcode reader can be used to read user information off. In addition, the method is known for its lack of flexibility and the limited storage information offered by barcode technology [19]. The RFID-based ETC involves the installation of an in-vehicle unit (IVU) on the windshield. An RFID reader is fixed on the toll plaza to read the RFID-tagged IVU. The IVU involved in this technique allows storing more information than the barcode technology. It also provides faster data transmission rates, and a moderate degree of security and reliability. The main drawbacks of the RFID implementation of ETC are that: (i) it has a limited communication range; and (ii) it is not cost-effective.

Automatic Number Plate Reader (ANPR) technology uses a stationary camera to record and identify the number plate of the vehicles passing through the toll plaza [20]. This works under a very strong assumption: that all vehicles have registered number plates bound to the vehicle owner's toll account. The identified number plate is cross-checked with those in the central database, and the toll fee is deducted from the vehicle owner's account. If the recorded number is not read properly, or not found in the records, it issues an enforcement violation alarm to alert the authorities. This way, it simultaneously achieves two objectives: automatic vehicle identification for the deduction of toll taxes, and issuing/recording violation alerts. If adopting highly-secure number plates that are very difficult to falsify, the problem of vehicle theft and fake number plate generation can also be handled by this system. On the other hand, ANPR is expensive, and its accuracy depends on environmental conditions, being less accurate under tempestuous weather [21].

WSNs support effective device monitoring and control, and they have been extensively adopted for different smart applications [23]. A WSN is a network of devices (denoted as nodes) which sense the environment and communicate the data gathered through wireless links [22]. These data are transmitted via multiple hops to a sink, also referred to as a controller or monitor, which can use it locally, or it is forwarded to other remote devices via the Internet. The sensor network is made up of a large number of sensor nodes, which are densely deployed either inside the entity, or very close to it. These sensor nodes perform different functionalities, ranging from remote sensing and data processing, to communication. An automated system can leverage the collaborative effort of large groups of nodes to improve system efficiency. In addition, several technologies exist for the implementation of WSNs, but they have major drawbacks which include, but are not limited to, complexity, large power dissipation, short distance, and networking in small scale. A new wireless network technology known as ZigBee is becoming increasingly popular for its low power dissipation and low speed [24].

III. Proposed ETC Framework for Smart and Connected Communities

Figure 1 shows the proposed framework for Cloud-based ETC system in smart and connected communities. The main features of this architecture include: automated vehicle detection; automated vehicle classification; automated toll collection; enforcement; database; cloud services; administrator end; and the mobile client.

A ZigBee device is located at the toll unit, acting as the Controller Unit (CU) while another ZigBee device is fixed to the vehicle. The CU and the In-Vehicle Unit (IVU) form a network of wireless sensor nodes. The IVU is powered by the battery of the vehicle. This network enables vehicle detection and classification, and establishes a communication link to the back-end of the system. Only registered IVUs are allowed to connect to the network for data communication. The IVUs are identified and verified by their unique Media Access Control (MAC) addresses.

The central database and the web server are hosted in the Cloud. Also, all the transactions, monitoring, and notifications that are involved in the system are controlled by the Cloud component. The Cloud platform offers the advantages of on-demand self-service, location-independent resource pool, pay per use, and elasticity. The Cloud component also include the web services that are used for data transmission between the ZigBee devices and the central processing unit.

The mobile client is basically designed for the vehicle owners. A unique account is created for vehicle owners on the mobile application to facilitate toll subscription, toll payment, and electronic receipt issuance. The mobile application can also be used for electronic transactions, subscription renewal, notification of toll payments, and for tracking toll payment history. The Android platform is recommended because of its wide user base, flexibility, and security. The movement of a pre-registered vehicle across the toll plaza triggers the deduction of the toll fee from the vehicle owner's subscription via the cloud component, and an acknowledgement is received as a push notification via the mobile application.

The web dashboard is an enhanced web application designed mainly for the maintenance and management of the ETC system. The enhanced web-based dashboard is used by the toll administrators for toll monitoring and management. This platform enables the toll management authority to track the activities at every toll booth. It can also be used to identify those trying to evade toll payment. The web dashboard provides an efficient platform for electronic audit of the toll fees collected over a particular period of time in a particular area.

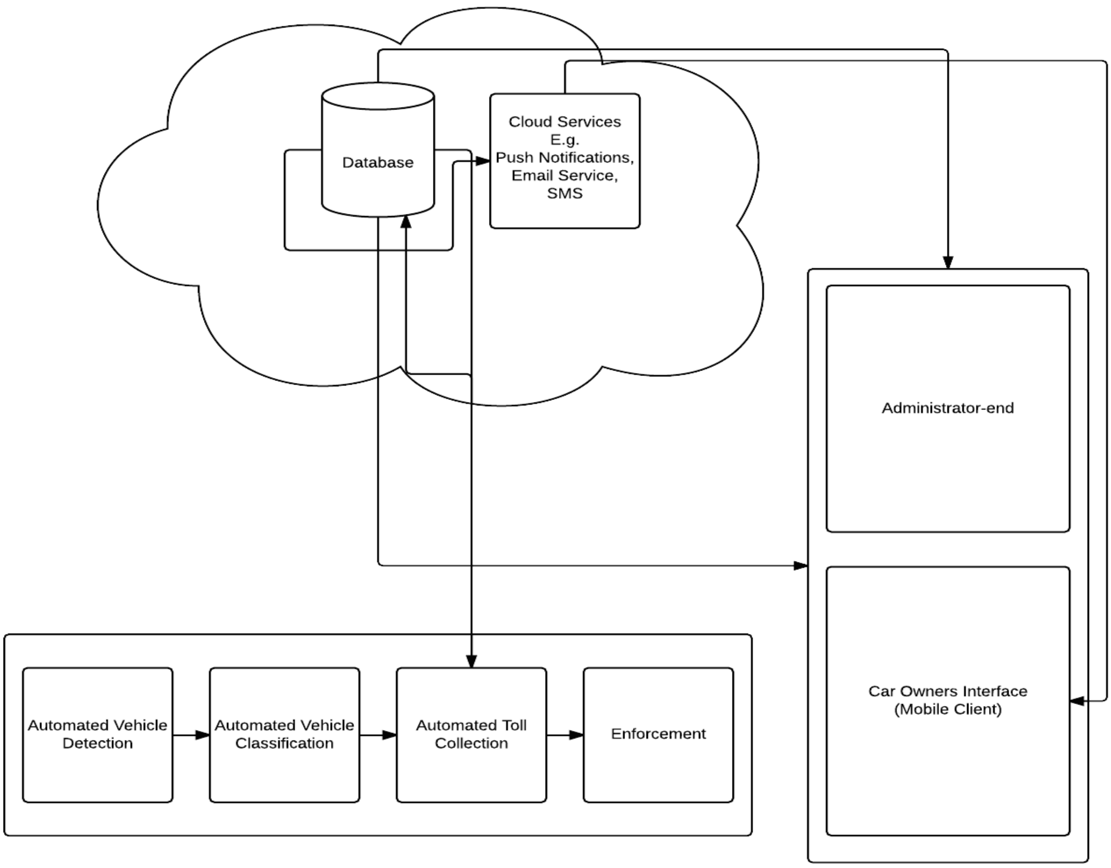

Figure 1: Proposed ETC Framework for Smart and Connected Communities

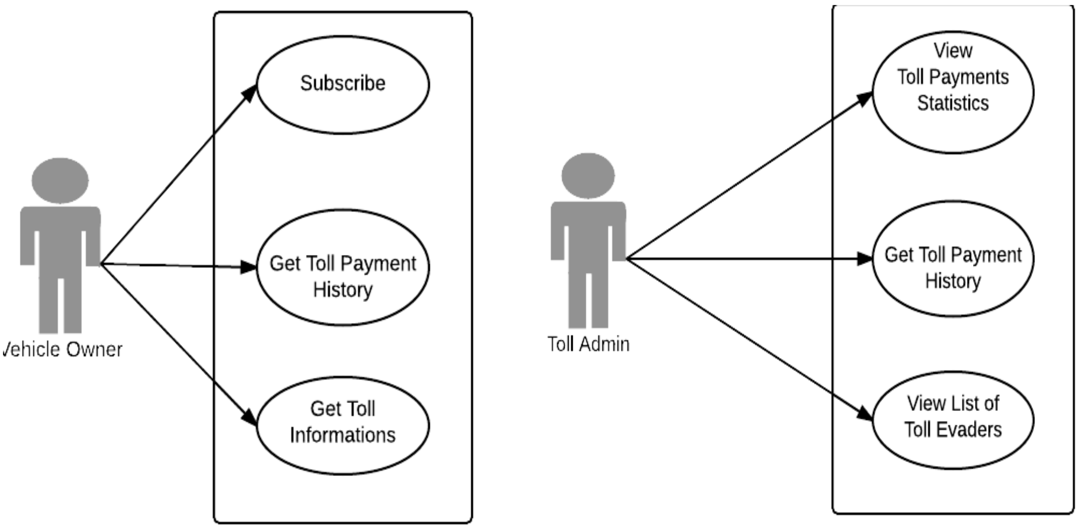

Figure 2: Use case diagram for (a) Vehicle Owners (b) Toll Administrators

IV. USE CASES

The use-case diagrams of the framework are shown in Figure 2. They represent all the interactions of the users with the system. There are two different users for the two application platforms: web and mobile. Due to the presence of uncontrollable factors in both the automated toll collection system and the WSN approach, several assumptions were made for the implementation of this architecture. We assumed a reliable broadband Internet access is available at the toll booths/plaza. We also assumed that there is a strict vehicle registration policy in place to ensure that no vehicle rovers the road network without been properly registered. Lastly, we assumed that there is an efficient legal platform that enforces toll payment and a fine for toll evasion.

The database is the bedrock of the information used by the entire system. The database must be designed to ensure data privacy and security. A relational form of database design is recommended because it helps at keeping complex data organized in a way that maintains non-replication. The design should consider critical entities of the system including the details about the user, the toll, the vehicle, the toll history, and the subscription.

V. Conclusion

This paper proposed an architecture for Electronic Toll Collection (ETC) in smart and connected communities. The main components of the intelligent system architecture are the wireless sensor nodes, web and mobile applications, and a cloud platform. The Wireless Sensor Network (WSN) enables vehicle detection and classification, and establishes a communication link to the back-end of the system. The central database and the web server are hosted in the Cloud while a mobile application is used for electronic transactions, subscription renewal, notification of toll payments, and for tracking toll payment history. In addition, a web dash board is provided for efficient toll administration. The implementation of this system will improve the toll collection efficiency in terms of speed and flexibility. Overall, the contribution of this work extends the frontier of WSNs to the domain of Intelligent Transportation System (ITS).

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