Queuing Free Smart Toll Gate based on Wireless Technology

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Abstract— **Highway is designed to be a traffic-jam-free road. However, the traffics are often jammed these days, especially during rush hour, causing fuel waste and air pollution. One of the reasons is the payment system which consumes time. Electronic Toll Collection system has been implemented in Indonesia to resolve this problem, but the traffic jam is still a common view in highways. It happens because the customers need to tap the electronic card to its reader until the payment transaction is verified and the bar is opened. This sequence of processes requires every vehicle to stop for a while. The accumulation of delay time is the main cause of queuing and traffic jam in highways. Further, the receipt for every transaction is still printed on a piece of paper which is eventually wasted and harm the environment. This article presents a prototype design of Queuing Free Smart Toll Gate system based on wireless technology. It can detect vehicles up to 40 km/h of speed within 3 meters radius. Service rate is less than 1 second per vehicle. Instead of using paper and ink and SMS, the payment notification is sent to the customer via the Internet. It is successfully received by customer's smartphone Telegram Messenger in less than 23 seconds after detection. This system can be an alternative solution to resolve traffic jam in highways, efficient and environmentally friendly. No more vehicles need to stop in toll gate, no more fuel wasting, no more air pollution, and no more paper trash at the toll gates.**

Keywords— Smart toll gate, wireless technology, queuing free, environmentally friendly,

I. INTRODUCTION

Highways are intended to be a traffic jam free road. It is expected to increase the convenience and shorten the travel time compared to the main road which is packed by various types of vehicles and pedestrians. However, recently, both expectations above are not felt by highway customers in major cities, because there is often a long queue at toll gates and traffic jam in the highway. The prime cause is the speed of vehicles coming into toll gates is greater than the speed of vehicles that can be served by the toll gates. Traffic jam or congestion at toll gates will harm the travelers due to wasted time, incendiary fuel combustion, air pollution, and vehicle exhaust smoke that disrupt the environment. These effects directly or indirectly can cause health problems for the human. [1]

Based on data from the Central Bureau of Statistics (BPS), the number of the vehicle registered in Central Java Police in the year 2015 consists of 82.684 passenger cars, 4.011 buses, and 33.512 freight cars. [2]. Meanwhile, highways in Central Java are not only used by Central Java residents but also travelers from other provinces. Looking at documents from the Department of Public Works of the Directorate General of Highways through Geometric Expressway for Highways [3], there is a specification by total 15 toll gates is 5.310 vehicles per hour with service time of 10 seconds. Considering the big difference between the number of vehicle and the capacity of toll gates, it is certain there will be an accumulation of delay time and congestion in toll gates, especially at rush hours such as departing to work and coming home.

One option to solve the congestion problem in the highway is using electronic toll gate. Some benefits of electronic toll gates are improving the efficiency of vehicle flow, saving time, and reducing pollution. Some countries have developed electronic toll gates commonly called the Electronic Toll Collection (ETC) system. It has been widely used by America, Europe, Asia, and Australia. [4]. Indonesia has been utilizing ETC which is called Gardu Transaksi Otomatis (GTO/ Automatic Transaction Gate). It improves the quality of toll gate services and toll road customer satisfaction. [5]. Existing GTO uses a debit card that should be tapped to the card reader for identification and payment process. It then prints payment prove on a paper which is not really cared for by the drivers and becomes trash around toll gates. This time-consuming process is still a prime cause of long queue and traffic jam at toll gates.

Currently, ETCs are developed using Radio Frequency Identification (RFID) technology in ARM type microprocessor [6, 7]. Combining with Global System for Mobile Communications (GSM), it can provide payment notification via Short Message Service (SMS). [8]. In the same concern, a queuing free automatic toll gate using microcontroller Arduino 2560 has been developed. Instead of debit card, it uses RFID active tag to identify the toll customers and do the payment. The detector is designed better to allow vehicle identification and payment just as it is passing through the toll gate. This method eliminates the queue at the toll gate. Payment notification is sent via SMS to mitigate paper trash problem around toll gates. [9]. Both [8] and [9] may save the use of paper and ink, but the cost of SMS is still relatively expensive.

This article presents a prototype design of Queuing Free Environmental Friendly Smart Toll Gate (Queen STG) system based on wireless technology. This prototype can detect vehicles with speed up to 40 km/h within a radius up to 3 meters. Service rate is less than 1 second per vehicle. Instead of using paper and ink or SMS, the payment notification is sent to the customer via data internet [10] which is much cheaper. It is successfully received by the customer's smartphone via Telegram Messenger in less than 23 seconds after detection. This system can be an alternative solution to resolve traffic jam in highways, effectively and environmentally friendly. No more queuing, no more traffic jam, no more fuel wasting, no more air pollution, and no more paper trashes at the toll gates.

II. Design of Queen Smart Toll Gate

The proposed Queen Smart Toll Gate system has two main parts, e.g. vehicle identification and data processing. Vehicle identification part has a role to detect vehicles entering the toll gate, store vehicle's identity number, and send the vehicle's identity data to the data processing part. The data processing part is responsible for data validation, storing data, and sending payment notifications to customers via Telegram Messenger. Figure 1 shows a general overview of the proposed Queen STG system.

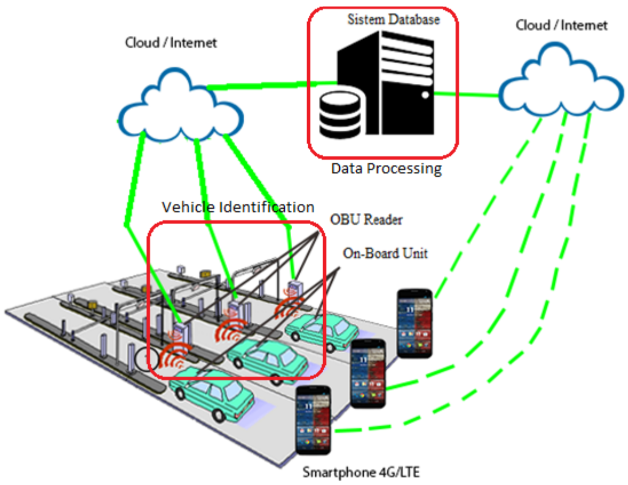

Fig. 1. Overview of the proposed Queen Smart Toll Gate system.

A. *Vehicle Identification*

The vehicle identification part consists of On-Board Unit (OBU) and On-Board Unit Reader (OBU Reader). OBU is installed in a vehicle. It serves reading passive RFID tags that carry vehicle identification number and sends this identity to OBU reader upon entering the toll gate. OBU Reader is a tool installed in the toll gate. It performs detection of any OBU-installed vehicles that enter the toll gates and sends data to the data processing part. The block diagram of vehicle identification part is shown in Figure 2.

OBU employs microcontroller ATMega8 to control the identification process and store information. RFID reader PN532 is used to read passive RFID tags as the identity of each vehicle. To send information to OBU reader, OBU uses transceiver module HC-11 which is set on 434 MHz radio frequency link. Circuit diagram of OBU and hardware realization are shown in Figure 3 and 4, respectively.

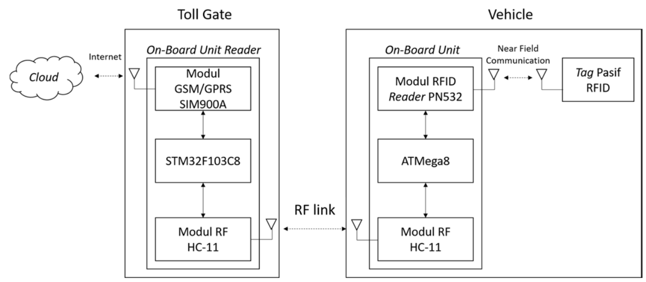

Fig. 2. Block diagram of vehicle identification part, consists of OBU reader and OBU. They communicate via RF Link 434 MHz

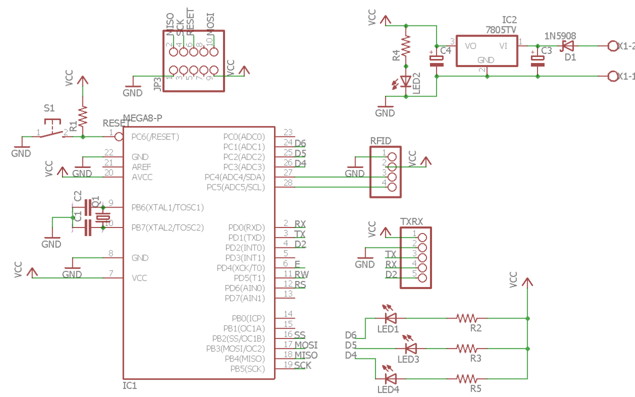

Fig. 3. Circuit diagram of OBU which is installed in the vehicle

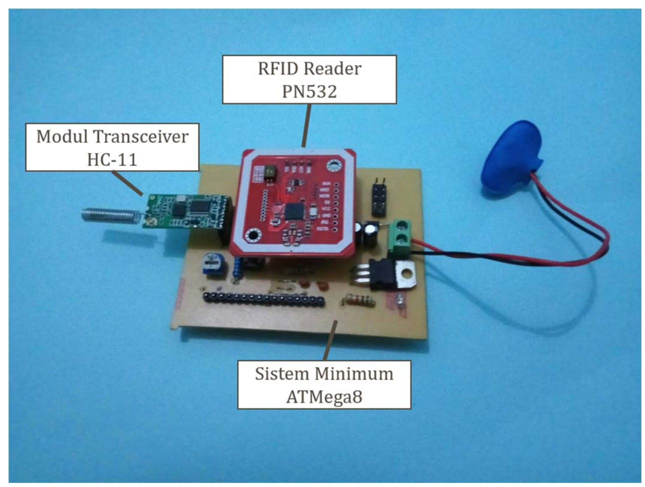

Fig. 4. OBU which is installed in the vehicle consists of ATMega8, RFID reader PN532, and Transceiver module HC-11 to send data to OBU reader.

OBU reader employs STM32F103C8T6 to manage identification process in toll gate side. OBU reader detects and receives transmitted data from OBU using Transceiver module HC-11 which is set on 434 MHz radio frequency link. GSM module SIM900A is used to transmit vehicle information to data processing server via the Internet. Circuit diagram of OBU reader and hardware realization are shown in Figure 5 and 6, respectively.

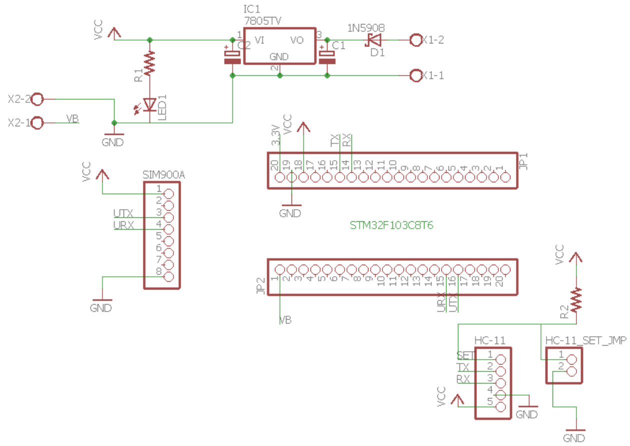

Fig. 5. Circuit diagram of OBU reader which is installed in the toll gate

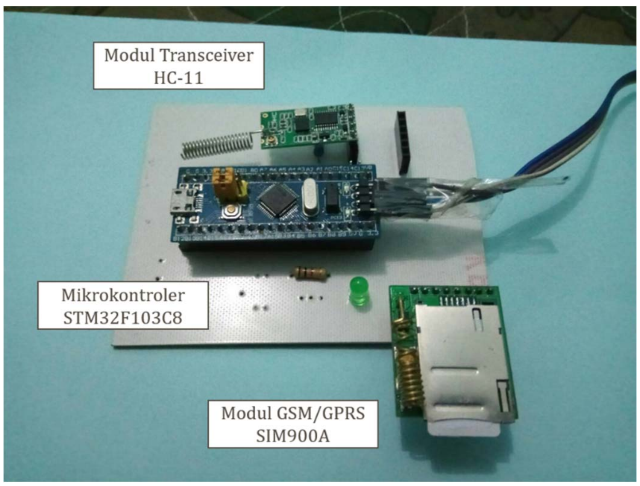

Fig. 6. OBU reader, installed in toll gate consists of Microcontroller STM32F103C8, Transceiver module HC-11 to receive data from OBU, and GSM/GPRS module SIM900A to send data to the Internet.

B. Data Processing

Data processing part is a database server which consists of the web server and database engine. It performs data storage, validation, and send payment notification to the highway's customer via the Internet using Telegram messenger. Figure 7 shows the block diagram of the data processing part.

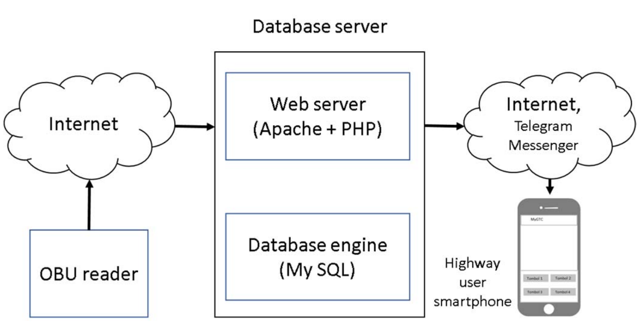

Fig. 7. Block diagram of the data processing part.

The database server receives data from OBU reader via the Internet using HyperText Transport Protocol (HTTP). The transmitted data from OBU reader consists of a toll gate name, vehicle RFID identity, and vehicle entering toll gate time. These data are written in JSON format. The database server separates this JSON data, validates for each RFID identity, stores data to the database, and sends payment notification message to registered Telegram account that matches with every RFID identity. This message is sent using the Telegram Application Programming Interface (API) which is already available on Telegram services. The notification message contains the toll gate name, the tariff information, and the time of entering the toll gate.

The database of the proposed Queen STG is designed using Relationship Database Management System (RDBMS). The database relation diagram which describes the relationship between tables of entities in the database can be seen in Figure 8.

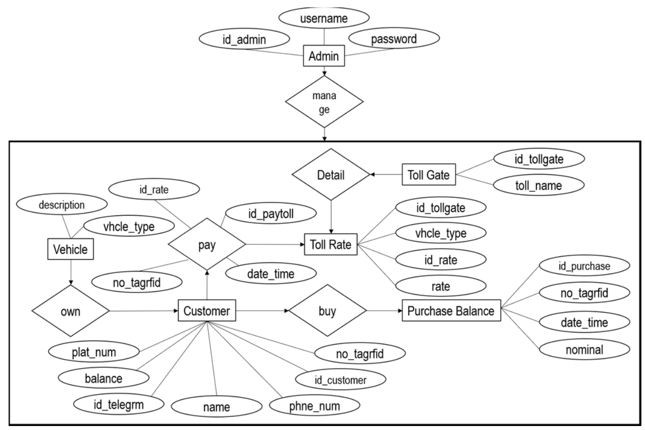

Fig. 8. Database entities relational diagram.

Tables of entities in the database are the admin, vehicle, customer, toll rate, toll gate's name, and purchase balance. Paying entity is related by a separate table because it has its own attributes. Attributes on the vehicle table are vehicle_type and description. Attributes on customer table are no_tagrfid, name, phone_number, id_telegram, no_plat, vehicle_type, and balance. Attributes on purchase balance table are id_purchase, no_tagrfid, date_time, and nominal. Attributes on the toll rate table are id_rate, id_tollgate, vehicle_type, and rate. Attributes on toll gate tables are id_tollgate and name_toll. Attributes on the paying table are id_paytoll, no_tagrfid, date_time, and id_rate.

C. System Flow

The proposed system assumes that all highway customers have an RFID card registered on the system along with an OBU installed on their vehicle. Customers who want to get a notification must register their Telegram account on the proposed system. Conveniences of highway can be enjoyed by customers who are fully registered on the system.

Highway's customers are required to turn on the OBU and ensure the RFID card is read by OBU before entering the toll gates. Customers can drive freely on the highway, pass through the toll gates without having to stop at each toll gates. Payment notifications will be sent to the Internet via Telegram. Highway charges are deducted from the balance or billed if the balance is insufficient. Customers can also view the remaining balance, last transaction, and contact customer service.

III. Run Test of Queen STG System

Some tests are conducted to the proposed Queen STG to measure its performance and match the desired requirements.

A. Power setting vs. reading distance

This test is conducted by varying the transmitted power of the transceiver module HC-11 and measuring the communication range between OBU and OBU reader. HC-11 has eight modes of power settings. Four of them are examined, i.e., 0 dBm, 5 dBm, 7 dBm, and 10 dBm. The nearest reading distance 0.7 meters is obtained at 0 dBm power setting and the furthest distance 6.7 meters is obtained at 10 dBm power setting. Table I lists all results of power adjustment to reading distance.

TABLE I. Power Setting vs. Reading Distance

Power (dBm)	Reading Distance (m)
0	0,7
5	1,3
7	4,5
10	6,7

The static 3 meters reading distance can be obtained by setting the transmission power of HC-11 at 7 dBm.

B. Vehicle speed vs. OBU identification

This test is needed to determine the maximum speed of OBU installed vehicle that can be identified by OBU reader which is located at a certain point. The mobile reading distance between OBU and OBU reader is set to 3 meters. The speed of OBU installed vehicle is increased until OBU reader cannot identify the OBU anymore. The power of transceiver module HC-11 is also varied to check the mobile reading distance between OBU and OBU Reader. Figure 9 shows the field testing of OBU power setting and vehicle speed variation vs. OBU identification while Table II lists the test results.

Fig. 9. Field testing of the prototype: OBU power setting and vehicle speed variation vs. OBU identification.

TABLE II. OBU Power, Vehicle Speed vs. OBU Identification

Speed (km/h)	OBU Power	*Tag* RFID Number	Identified as	Result
10	0 dBm	e2960207	-	Failed
	5 dBm	e2960207	-	Failed
	7 dBm	e2960207	e2960207	Detected
	10 dBm	e2960207	e2960207	Detected
20	0 dBm	e2960207	-	Failed
	5 dBm	e2960207	-	Failed
	7 dBm	e2960207	e2960207	Detected
	10 dBm	e2 960207	e2960207	Detected
30	0 dBm	e2960207	-	Failed
	5 dBm	e2960207	-	Failed
	7 dBm	e2960207	e2960207	Detected
	10 dBm	e2960207	e2960207	Detected
40	0 dBm	e2960207	-	Failed
	5 dBm	e2960207	-	Failed
	7 dBm	e2960207	e2960207	Detected
	10 dBm	e2960207	e2960207	Detected
50	0 dBm	e2960207	-	Failed
	5 dBm	e2960207	-	Failed
	7 dBm	e2960207	-	Failed
	10 dBm	e2960207	-	Failed

Table II shows that setting the OBU power at 0 dBm and 5 dBm result in a failed identification of the RFID tag. After setting the OBU power to 7 dBm and above, the RFID tag can be detected up to vehicle speed 40 km/h. However, the identification is failed when increasing vehicle speed to 50 km/h.

C. The time between OBU is detected and notification is received

This test is performed to measure the total time required from the OBU is detected by OBU Reader to Telegram notification is received by the customer. The test consists of three observed times, i.e., (A) the time OBU is detected by OBU Reader, (B) the time transmitted data from OBU Reader is received by the database server, and (C) Telegram notification time is received by the customer. This test scenario is illustrated in Figure 10.

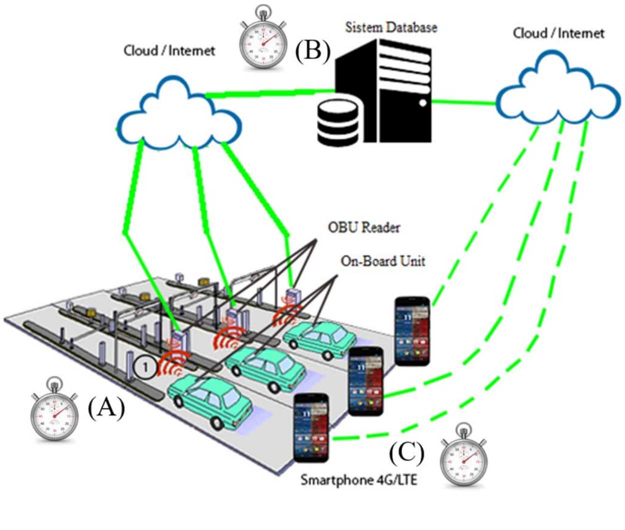

Fig. 10. The scenario of time required measurement, consists of three observed times: (A) OBU detection, (B) data received by the database server, and (C) notification is received by the customer.

From these observed times, the time taken from the OBU is detected until data is received by database server is (B - A), the time needed from the data received by the server until the notification is received by the customer is (C - B), and the total time required from the OBU is detected until notification received by the customer is (C - A). Time (A) and (B) is observed from PuTTy, while time (C) is observed from the time the notification is received by the customer's smartphone. Table III lists the observed times.

TABLE III. TIME REQUIRED FROM OBU IS DETECTED TO NOTIFICATION IS RECEIVED BY CUSTOMER

Test No.	(A) hh:mm:ss	(B) hh:mm:ss	(C) hh:mm:ss	(B-A) (s)	(C-B) (s)	(C-A) (s)
1	06:32:25	06:32:40	06:32:47	15	7	22
2	06:33:06	06:33:15	06:33:21	9	6	15
3	06:33:29	06:33:40	06:33:46	11	6	17
4	06:33:50	06:34:10	06:34:16	20	6	26
5	06:34:20	06:34:40	06:34:46	20	6	26
6	06:34:57	06:35:10	06:35:16	13	6	19
7	06:35:19	06:35:45	06:35:51	26	6	32
8	06:38:22	06:38:45	06:38:51	23	6	29
9	06:38:59	06:39:15	06:39:21	16	6	22
10	06:39:27	06:39:40	06:39:46	13	6	19

Table III shows that from 10 times of testing, the average time required from the OBU is detected until data is received by the database server (B - A) is 16.6 seconds. This time is acceptable because the time interval for sending data to the server is 30 seconds. The average time required from the data is received by the server until the notification is received by the customer (C - B) is 6.1 seconds. Finally, the average total time required from the OBU is detected until the notification is received by the customer smartphone (C - A) is 22.7 seconds. Screenshot of received notification in customer smartphone using Telegram messenger is shown in Figure 11.

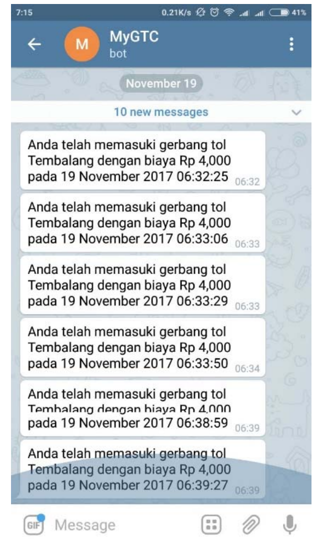

Fig. 11. Screenshot of notification which is received by highway customer's smartphone from the Internet via Telegram messenger.

D. Customers Testing

This testing is done by a vehicle carrying OBU passes through the OBU Reader. Five RFID tags for five customers are already stored in the database. Each customer drives the vehicle at speed around 40 km/h. The power on the OBU transmitter is set to 7 dBm. The distance between the vehicle and OBU Reader is about three meters. OBU on a vehicle that has passed and detected by OBU Reader is indicated by a combination of green and red LEDs. PuTTy terminal connected to the OBU Reader is displaying the detected RFID tag's number and send this data to the database server. After data processing, each customer receives a notification from database server via Internet using Telegram messenger. The results for the overall system test are shown in Table IV.

TABLE IV. PERFORMANCE EXAMINATION OF QUEEN STG FOR DIFFERENT CUSTOMER

Customer Name	Vehicle speed	RFID tag No	Identified as	Notification
Yusuf Baharuddin	40 km/h	86ffecd5	86ffecd5	Received
M.Fatkhurrahman	40 km/h	e2960207	e2960207	Received
Fuad Ashabus	40 km/h	e2f36e85	e2f36e85	Received
Arisla Choiruddin	40 km/h	5e29273b	5e29273b	Received
Rafi Dhega	40 km/h	864ab2d5	864ab2d5	Received

E. Sequential Vehicles Testing

This test is performed to measure the service rate of the proposed Queen STG system. Service rate means the readiness of the system to serve (detect) the next coming vehicle after detecting the current passing vehicle. The ability in detecting more than one vehicle entering the OBU communication range is examined. Two vehicles each carrying OBU pass through

OBU Reader sequentially. The distance between the two vehicles is one meter and the distance to OBU Reader is three meters. Both vehicles run in speed 15 km/h. The proposed Queen STG System can detect both vehicles, do the data processing, and reduce the balance of each registered account then send notification. Both of related smart phones receive notification of passing the OBU reader, successfully. This examination is conducted five times. Table V shows the results.

TABLE V. SEQUENTIAL VEHICLES TESTING

Test	RFID tag No	Identified as	Speed (km/h)	Detected time (A)	Notification
1	86ffecd5	86ffecd5	15	08:32:20	Received
	e2960207	e2960207	15	08:32:20	Received
2	86ffecd5	86ffecd5	15	08:43:06	Received
	e2960207	e2960207	15	08:43:06	Received
3	86ffecd5	86ffecd5	15	08:48:29	Received
	e2960207	e2960207	15	08:48:29	Received
4	86ffecd5	86ffecd5	15	08:53:50	Received
	e2960207	e2960207	15	08:53:50	Received
5	86ffecd5	86ffecd5	15	09:13:02	Received
	e2960207	e2960207	15	09:13:02	Received

The service rate of the proposed Queen STG system can be determined from the detection time (A) which is taken from the time stamps of every notification. In Table V, two vehicles are detected in the same time (second). In other word the proposed system can detect two vehicles within one second. This means the service rate of the proposed Queen STG system is less than one second.

F. Different Smartphone Operating System Testing

This testing is conducted to check the Telegram server response time to different smartphone operating systems within the same communication network. The network used here is 3G. This test involves three different smartphones, by displaying the time between customer sending messages with bot replying. Table VI lists the results.

TABLE VI. DIFFERENT SMARTPHONE OS TESTING

Test	Action	Smartphone OS		
		Oppo A37	Xiaomi Redmi 3x	iPhone 6s
1	Add a bot and start a conversation by pressing/start	4,9 s	6,5 s	6,3 s
2	Displays keyboard to verify the phone number	4,2 s	4,1 s	4,8 s
3	Send a phone number to retrieve chat id.	5,4 s	5 s	5,5 s
4	Checking your existing balance	3,8 s	4,4 s	4,8 s
5	Display a transaction check keyboard	4,3 s	4,8 s	3,9 s
6	View toll payment report	3,7 s	4,5 s	4,5 s
7	View balance purchases report	3,5 s	4,5 s	5 s
8	Pressing the "Contact Us" button	3,1 s	3,3 s	4,1 s
9	Pressing the "Help" button	3,5 s	4,4 s	4,7
10	Pressing the "Back" button	4,3 s	4,3 s	4,3 s
11	Cars pass through the toll gate, users get notifications	3,8 s	4 s	4,5 s

From the average time of the bot response above, it can be concluded that the different smartphone OS gets almost the same replying time from the proposed system.

The proposed system is still in prototype mode which is still developed and added with more features. For the time, the system was tested at the laboratory field. Next testing will be in the real highway after get the permission letter from the highway provider agency. The proposed system is using a serial number of RFID only for identity purpose. After storing this serial number into the OBU, the RFID tag is no longer needed. This identity number can be changed by any number as long as it is unique. The credit balance is made online so that it can be checked, debited, and recharged online without the need of reader/ writer unit. The conventional system is using the smartcard, so that no connection to the server is needed. However, to recharge the credit balance, the customer needs a reader/ writer unit which is more complicated. Further, to validate system performance, a queue model (e.g. Poisson distribution) will be taken into consideration for next work.

IV. CONCLUSION

We have developed a prototype of Queuing Free Environmental Friendly Smart Toll Gate based on wireless technology. The speed of the vehicle that can be served by this prototype is up to 40 km/h with the distance between the vehicle and OBU Reader is 3 meters. Service rate is less than 1 second per vehicle. Payment notification is successfully sent by the system to the Internet and is successfully received by registered smartphone via Telegram social messenger less than 23 seconds depends on communication network conditions. Sequential vehicles also can be handled successfully by the system. Further, the operating system of the smartphone does not affect the performance of the Telegram sever since the response time does not show any significant difference. These results demonstrate that the prototype of Queen STG system works well and is eligible to be an alternative solution to resolve traffic jam in Indonesian highways, effectively and environmentally friendly. No more vehicles need to stop in toll gate, no more fuel wasting, no more air pollution, and no more paper trash at the toll gates.

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