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5.8 GHz ACTIVE RFID TECHNOLOGY IN MULTILANE FREE FLOW (MLFF) FOR ONLINE ELECTRONIC TOLL COLLECTION SYSTEM AT MALAYSIA HIGHWAY

N. A. GHAZALI[1], WIDAD ISMAIL[2], ZAINI A. HALIM[3]

[1, 2, 3] Auto-ID Laboratory (AIDL), School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, Nibong Tebal, Seberang Perai Selatan, Pulau Pinang, Malaysia.

Tel: 604-5996050, Fax: 604-5996909

E-mail: [1]lin_adln@yahoo.com, [2] eewidad@usm.my; [3] zaini@usm.my

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Abstract *This paper proposed a multilane free flow (MLFF) electronic toll collection (ETC) system using radio frequency identification (RFID) technology. There are various technologies have been used to realize the MLFF ETC system around the world. The proposed RFID system uses tags that are installed in the vehicles that stored unique information about the vehicle such as vehicle's ID and registration number. This unique information will be read by the wireless sensor network (WSN) based RFID reader installed at the road side of the highway. The proposed system eliminates the need for motorists to slow down or stop for a while for the purposed of online toll collection. The user can maintain their vehicle speed during the data transmission process. The proposed solution is taking into consideration of application in Malaysia highway and can also be good guidelines for other transportation system that requires online toll collection system since the proposed system is considering WSN implementation for the future of internet of things (IoT).*

Keywords: *Online electronic toll collection (e-payment), RFID, multi-lane free flow, long range RFID, WSN, IoT*

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1. Introduction

Most of the existing highway toll collection systems require vehicle to make a short stop at the toll plazas in order to make a payment for the toll charge. This conventional system causes traffic congestion and contributes to the air pollution [1-2]. There are two main types of electronic toll collection (ETC) systems existed which are single-lane and multi-lane free flow. The multi-lane free flow (MLFF) is the system that been designed to keep traffic flowing in order to achieve maximum throughput on the highway, helps to reduce traffic congestion and environmental friendly [3]. With the MLFF, the vehicle free to run at any lanes without the need to slow down or stick to specific lane when approaching toll booth for road charging. The implementation of the MLFF will give the enormous benefit to both highway user and operators. Nevertheless, the implementation of MLFF for highway required electronic toll collection (ETC) systems as well. Therefore, there is a need to also implement the ETC system as web based system that requires accessibilities of the hardware system that can support the internet functionality through internet of things technology [4 - 5].

ETC is the combination of techniques and technologies that enable automatic toll collection systems. It has been studied worldwide to be used in the highway, tunnel and bridge [6]. The aim of this technology is to eliminate delay on the highway. The obvious benefit of the ETC is non-stop toll collection service. Thereby, it can improve the efficiency of the highway. In order to realize the system of ETC, the vehicle identification technology is required. Radio frequency identification (RFID) was seen as the best candidate for ETC because it has the capability to identify the vehicles passed without requiring any action by the driver.

RFID technology utilized radio waves to automatically identify people or objects without requiring any contact and a line of sight. It is use to communicate digital information between a stationary and moving object or between moving object and moving object [7]. An early work exploring RFID technology was by Henry Stockman in 1948 [8]. Now, the RFID technology has been implemented in various applications and growing rapidly.

The complete RFID system consists of reader, tag and host computer [9] as shown by Figure 1. A tag is also known, as transponder is the device that stores unique identification information of objects. It can be classified as active and passive tags. A passive RFID tag has no internal power source while an active tag has its own power source. Both types of the tags have its particular pros. The internal power source of the active tags allows the tags to have the longer reading range as compared to passive tags. An active RFID system has a great advantage when tracked large or valuable items over long distances.

A reader or interrogator comprises of an antenna to receive and transmit information from the tags. The reader radiates radio waves through the antenna and detects radio waves reflected back from the tags when the tag was being placed within the range of the reader. The range of the reader is subjected upon its operational frequency. The reader could be handheld or fixed device. The host computer is providing an interface that enable information processing to be used by the end user.

In this paper the MLFF highway system based on 5.8 GHz active RFID systems has been proposed. The motivation to use 5.8 GHz active RFID is due to its obvious range of advantages and availability at ISM frequency band, high data transfer, to avoid high traffic level on other frequency band and has better bit error rate because of less crowded band. The proposed system is expected can be implemented in the future highway system in Malaysia for online ETC system.

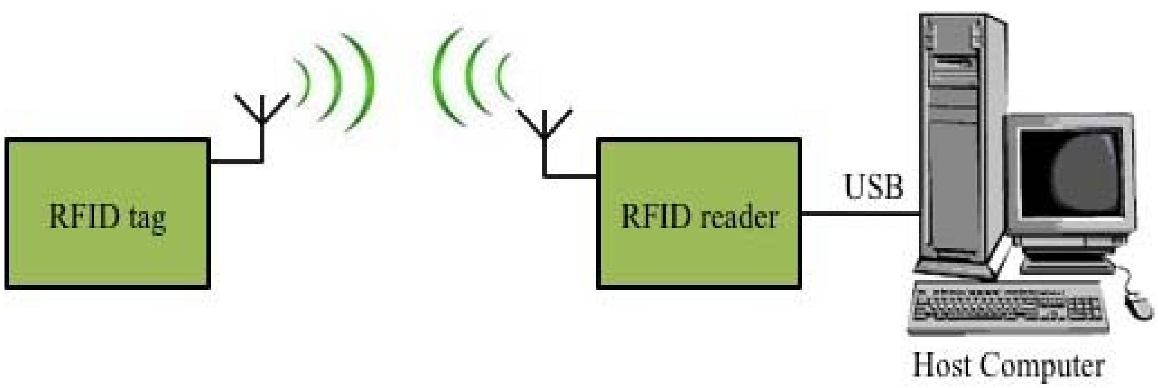


Figure 1: General Block of RFID System

2. Related Works

There are several works have been proposed or being used globally with different technologies for MLFF based on existing vehicle identification technologies. As an example, the system described in [2], [10] – [13] proposed the implementation of MLFF using different technologies. The system evaluated by Mustafa et. al in Thessaloniki, Greece [10] has been in six lane rural arterial along 24 km. The designed system operates at 5.8 GHz microwave link composed of overhead gantry covering three lanes motorways, transceivers and control unit. There two stage of data transmission in the proposed system. The first stage is between the in-vehicle equipment and transceiver at the entrance point while the second stage is between in-vehicle equipment and the second transceiver at the exit point.

The system proposed in [2] employed the communication in the millimeter-wave range to develop a radar-based system for MLFF. The proposed architecture used different frequency band in different traffic lanes and suitable to be implemented in either passive or active on-board unit (OBU) system. The proposed architecture for MLFF combines two frequency multiplexing and two techniques widely used in radar systems namely, pulse ranging and fine target-direction determination.

Another short range communication system that has been use to implement MLFF is infrared. The infrared is popular to be applied in ETC due to their lower cost and simpler technology compared to other short range communication technology. The ETC system proposed in [11] used infrared technology with improvement on radiation pattern of the emitting module in order to obtain extended communication region under high signal attenuation. The authors proposed the OBU designed with two typical LEDs with half-intensity of 22^o and 10^o.

In [12] the ETC system based on dedicated short range communication (DSRC) has been discussed. The ETC system in Austria, Czech Republic, Norway and France use the DSRC technology at 5.8 GHz frequency band. The toll system is an open system with one gantry at entrance and exit point which required two stage data communication. The system requires the installation of the OBU on the windscreen of the vehicles.

An alternative to the aforementioned to the short range communication system proposed by [12] use innovative combination of mobile telecommunications technology (GSM) and the global positioning system (GPS) to design an ETC system for Republic of Poland. The OBU will send the total kilometer driven by the vehicle, calculated the toll payment based on the toll rate with the assistance from the GPS satellite signal and other positioning sensors to the ETC processing center for further processing by GSM.

3. Methodology

The first ETC system in Malaysia was implemented in 1995 along 22 km out of 848 km expressways. Currently, the whole stretch of 1459 km expressways are equipped with a single lane ETC system consists of TouchNGo and SmartTAG [13]. Both TouchNGo and SmartTAG use IR technology, which require line of sight to enable communication. The future plan of Malaysian highway authorities is to implement MLFF because its offer much greater advantages such as reduce congestion at toll plazas, increased road safety and environmental friendly [13] and improve the toll collection through online electronics payment system [14].

This paper proposed the MLFF using RFID technology rather than IR technology. The proposed MLFF can communicate wirelessly in order to exchange the information by the fixed device in the vehicle and the device by the road side of the highways by increasing the functionality of machine-to-machine communication (M2M) for internet of things. It means that the electronic toll collections system can gathered the data through the proposed hardware system directly to the internet without human intervention as conventional system that requires manual monitoring and data capture. The proposed system composed of control system, reader and tag as illustrated in Fig. 2. The tag is the device installed in a vehicle to send the unique vehicle identification to the reader. The vehicle identification is collected and ready for transmission to the reader once the vehicle is in the interrogator zone. The reader is installed at the roadside of the highways as the replacement of the toll plazas. The reader’s collected data such as vehicle’s ID and registration number will be transmitted to the control system for data processing and storage.

The reader will be installed at the entrance and exit point of the highways. At the entrance point of the highway, the reader will capture the vehicle’s ID and send it to the control system that can be connected to the internet for e-payment. When the user want to exit the highways, the other reader will capture again the vehicle’s ID and send it to the control system. The system will calculate the kilometers driven and payment. With the proposed system, the highway users do not have to slow down or stop for a while at the toll plaza to make a payment and can change travel lanes during data transmission between the tag and the reader.

The RFID system is composed of two principal components which are tag and reader. These two principal components are powered by 3.3 V. Figure 2 illustrated the block diagram of the proposed active RFID reader, while Figure 3 shows the block diagram of the proposed active RFID tag. The reader consists of RF module, Serial UART module, led indicator and the interface to connect to the host system. The tag contains a microcontroller to control the data flow between interface, RF module, led indicator and ON button. To supply low voltage to the board, a L7805 and LM1117 are used to regulate a 9 V to 5 V and 3.3 V DC supply respectively. The proposed tag is powered by 9 V alkaline battery. Communication of the proposed active RFID is based on Zigbee technology. This technology can support mesh network and capable to build its own network in long range.

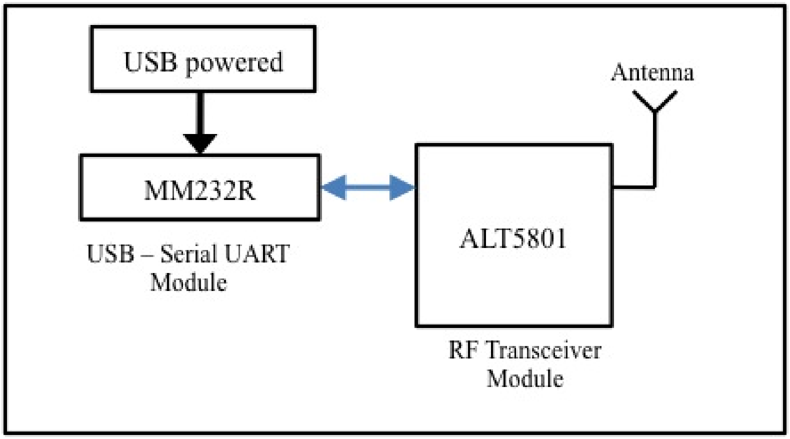


Figure 2: Block diagram of proposed 5.8 GHz active RFID reader

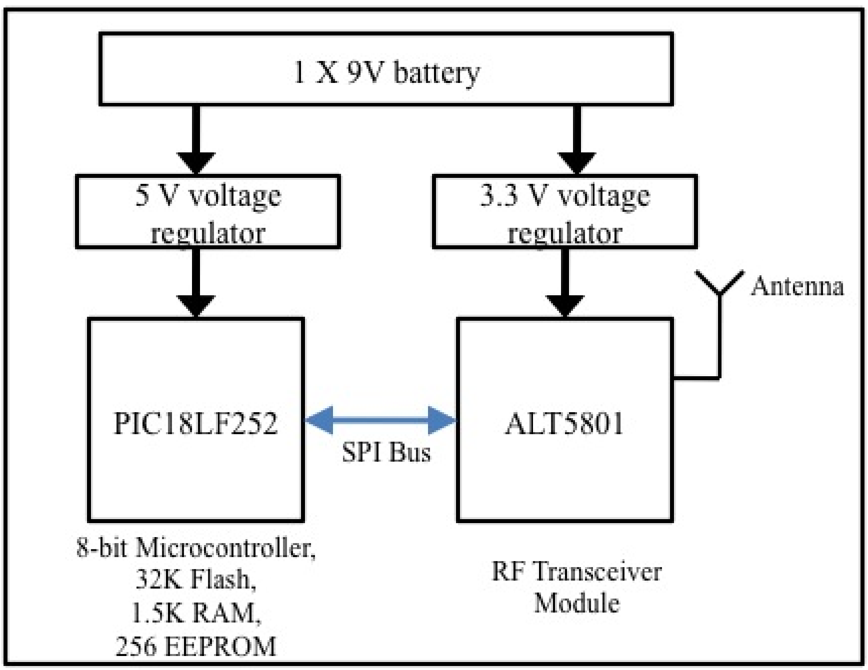


Figure 3: Block diagram of proposed 5.8 GHz active RFID tag

The proposed active RFID tag can be automatically put in the sleep mode and wake-up upon the request from the reader. The proposed reader will send the request data to the tag and the tags within the interrogator zone will respond to the reader, as illustrated in Figure 4. After certain period of time, the tag will automatically operate in sleep mode. The power consumption of the tags during transmission heavily depends on the distance between the reader and the tag, the longer the distance, the higher the power consumption of the tags.

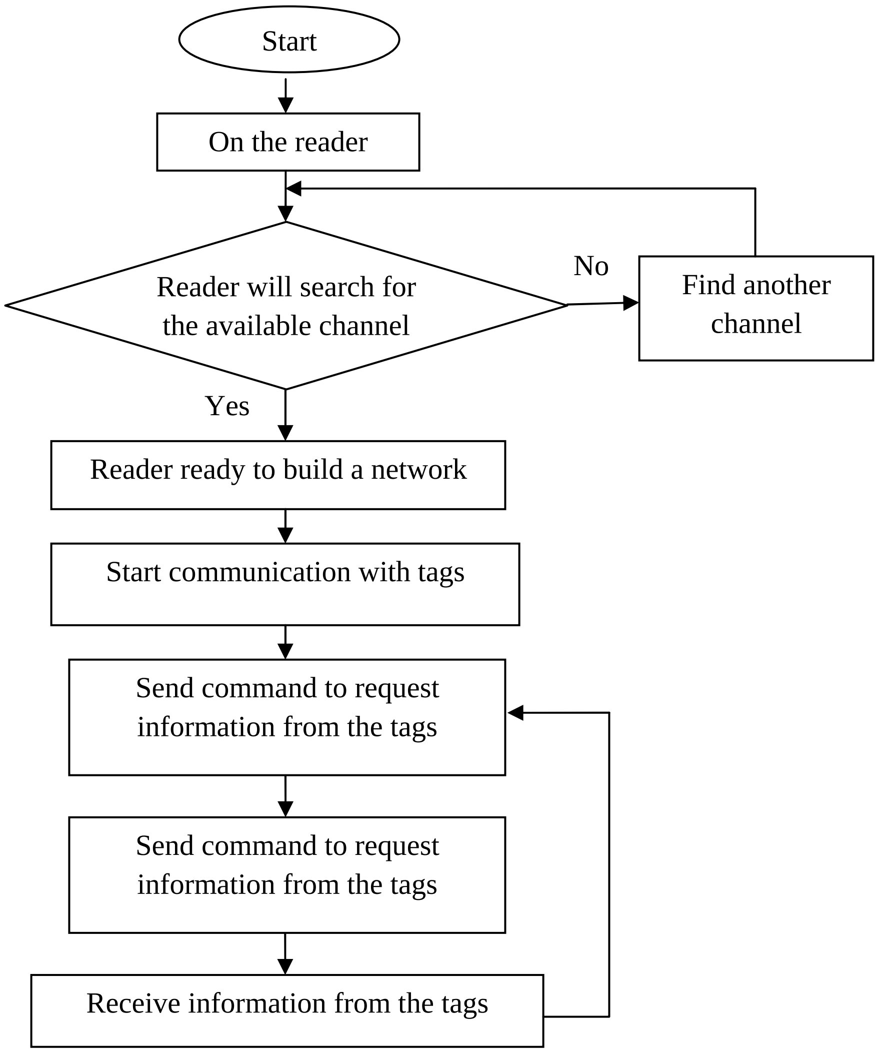


Figure 4: Operational flowchart of proposed RFID reader–tag communication

4. Experiments and Results

In this section, some result from a preliminary performance evaluation of active RFID system is presented. The testbed for the measurement is also being reported.

A. Power Consumption Measurement Results

The sleep mode function enables the tags to shut down the unused modules in thus saving power. Table 1 shows the different power consumption of the different operation mode.

Table 1: Power Consumption in RF

Mode	**Typical**	**Unit**
Sleep	< 3	µA
Receive	90	mA
Transmit	150	mA

The tests were carried out when the tag is in receiving and transmission cycle as well as sleep mode. Since the occurrence of the tag is complicated to estimate, the analysis of the current consumption is based on periodic transmission is set to occur in hourly basis. The average current is calculated from the usage percentage and current consumption of each mode [16]. Table 2 illustrated the average measured current consumption at different mode.

Table 2: Measured current consumption of the tag for a period of an hour

Mode	% of Time	mA	[% of time*mA]
Sleep	99.997	0.02	0.019999
Receive	0.0028	60.04	0.00168
Transmit	0.0002	79.73	0.000159
Total	100	0.021838	

B. An active RFID Tag Battery Life Estimation

The tags are equipped with a single 9 V battery with 550 mAh and with an average current consumption of 0.02184 mA, the battery life span it is estimated by the following calculation [16].

$$\frac{550\ \text{mAh}}{0.02184\ \text{mA}} = 25183\ \text{hours} = 1049\ \text{days}$$

Therefore, the battery can last for about 1049 days or 2.87 years. The result is competitive with other designs. For instant, tag designed by [17] consumed 1.4 mW in active state and has a battery lifetime of 920 days using a 3V lithium cell (calculated for CR2032, 1620 Joule). Moreover, tag designed by [18] consumed 15.1mA, 13.3mA and 92uA respectively for transmitting, receiving and standby. By using the battery with 1200 mA/h capacity the lifetime of the battery is about 1.5 years.

C. Read Range Measurement Results

A few measurements were conducted to determine the maximum distance at which a proposed tag is readable by a proposed reader. The measurements were conducted in two different scenarios in line-of sight (LOS) and non-line-of-sight (NLOS) indoor and outdoor environment and measure the performance of the radio signal strength in term of LQI value.

Figure 5 and 6 shows the measurement of the LQI versus the distance between the proposed tag and reader in outdoor and indoor environment. It can be seen that the LQI value is degraded when the proposed tag moved away from the proposed reader as defined by Friss Equation.. The NLOS reading degraded in very short distance for example at the reader with less than 50 m due to poor signal strength in high attenuation. The Friss transmission equation is denoted as follows:

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2} \quad \text{or} \quad P_T = \frac{P_R (4\pi R)^2}{G_T G_R \lambda^2} \tag{1.0}$$

Where,

P_R = Received power

P_T = Transmitted power

G_T = transmitter antenna gain,

G_R = receiver antenna gain,

λ = wavelength,

R = distance separating RFID tag and RFID reader antennas,

From equation (1), it can be seen that received, P_R is decreased with an increased distance, *R*.

The maximum distance where it is possible to read the tag by a RFID reader in an approximated line-of sight (LOS) and non-line-of-sight (NLOS) indoor and outdoor environment also been recorded. The result of the experiment is shown in Table 3. The RFID performance degrades when used in a confined area such as in the laboratory.

Table 3: Result of maximum read range measurement

Environment	Indoor		Outdoor	
Propagation	NLOS	LOS	NLOS	LOS
Maximum Distance (m)	46	225	165	425

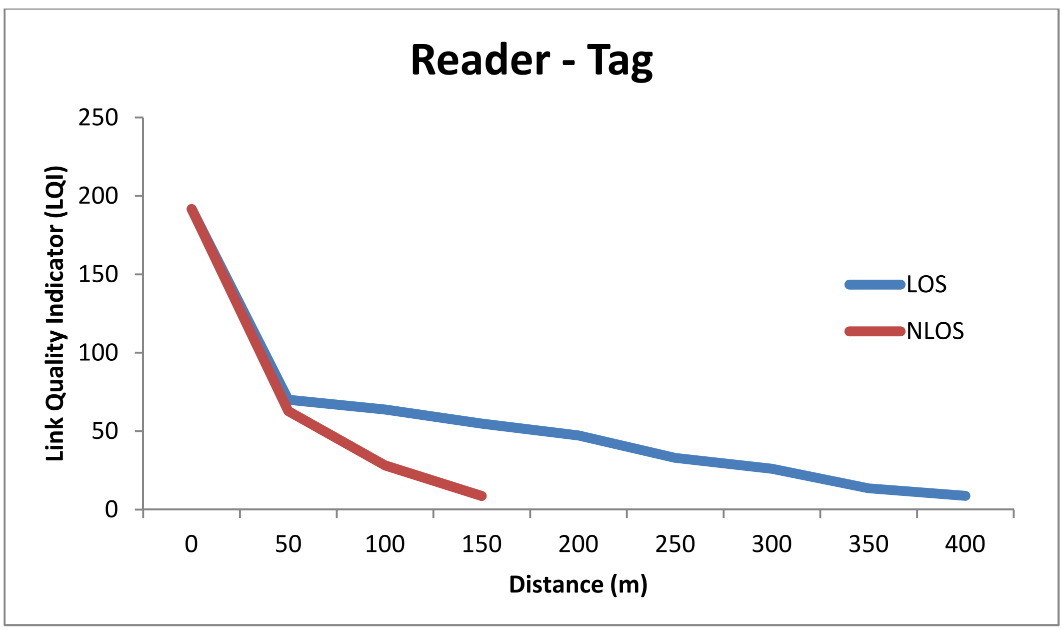


Figure 5: The LQI as the function of distance for outdoor environment

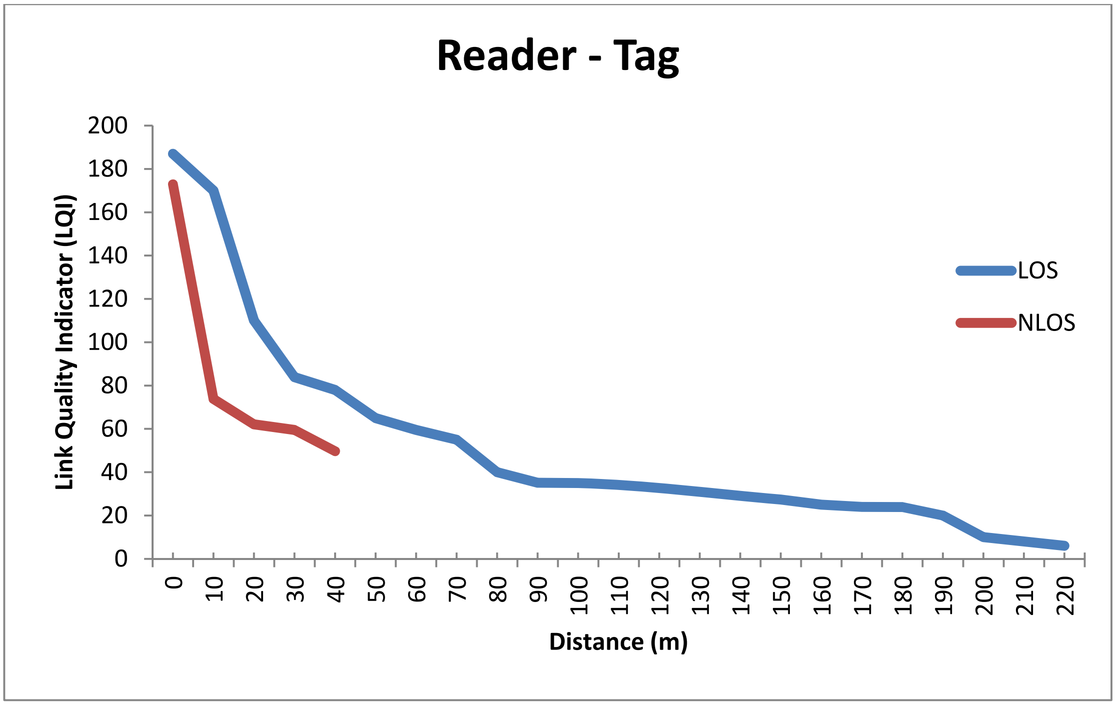


Figure 6: The LQI as the function of distance for indoor environment

D. Speed Test Results

The characteristic when the proposed tag is attached in the moving vehicle at different speed also have to be accounted. The test was carried out in the area of a straight road as shown in Figure 7. The reader has been installed at the roadside at a height of two meters and the tag was attached to the moving vehicle as shown in Figure 7 and 8 respectively. The test was repeated for a different speed start at 30 km/h to 110 km/h in interval of 10 km/h.

Figure 7: Speed test environment

Figure 8: The location of RFID tag in the car

Figure 9 shows the measurement of LQI versus the vehicle speed installed with the proposed tag inside a vehicle. When the vehicle is moving at the high speed, the LQI values is decreased. It shows that the vehicle speed is affected by the LQI strength. This means that the vehicle speed has affected the transmission rate because the transmitted data may need to be more sensitive when the vehicle is moving at higher speed. The maximum speed at which a proposed tag is detectable cannot be conducted due to range limitation. However, the estimated maximum vehicle speed that is detectable by the reader is approximately 300km/h at 250 kbps as shown by Figure 10 which took the tested speed based on the work by [13].

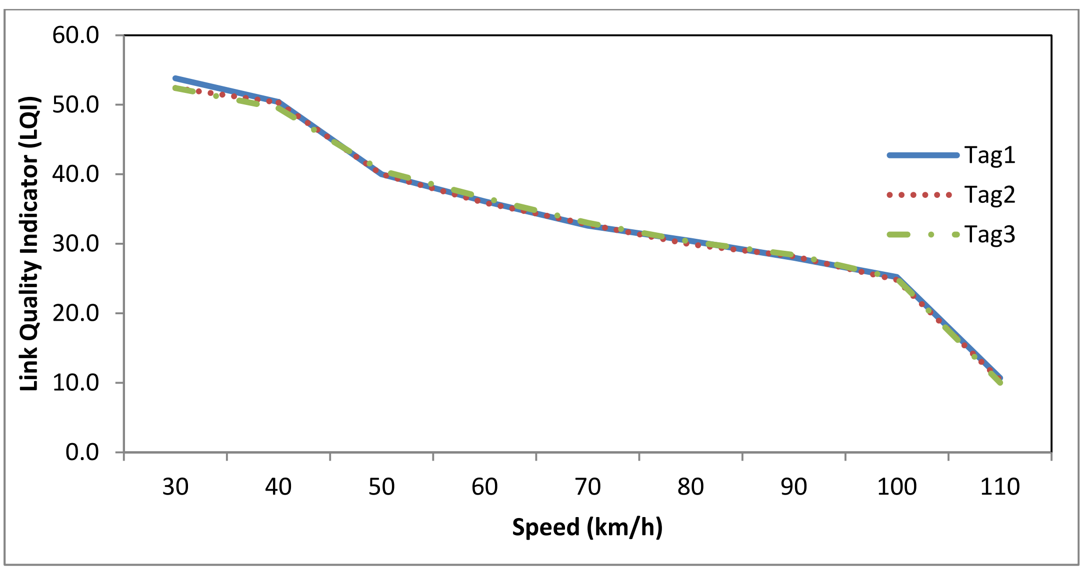


Figure 9: Measured LQI as a function of vehicle speed

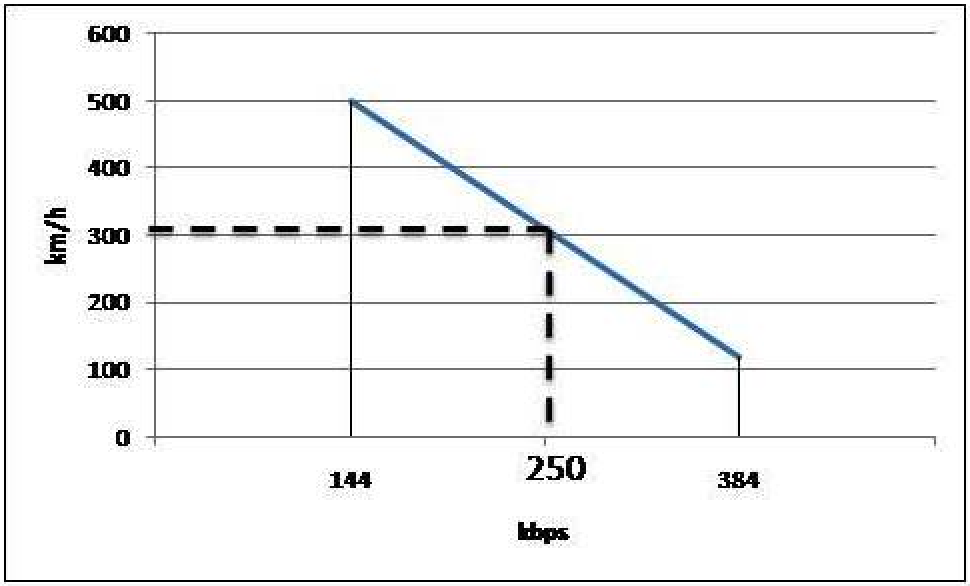


Figure 10: Estimation of vehicle speed as function of kbps based on [13]

5. Discussions

The paper presents the developed a 5.8 GHz RFID System which can be applied to improve the current Electronic Toll Collection (ETC) system in Malaysian Highway with the following features:

i. Virtually non-stop MLFF system that will reduce traffic congestion during peak hours and festive seasons due to toll plazas and manual payment.
ii. Replace current prepayment system in stages with e payment system following the global standard.
iii. Use a single tag inside car where it can reduce the cost.

In addition, some technical advantages to the highway authority and users are summarized which is illustrated in Table 4 below.

Table 4: Technical advantages of adopting the proposed system

TO HIGHWAY AUTHORITY	TO USER
➢ Low power consumption ➢ Non line of sight reading ➢ Read and write capability ➢ No toll plaza	➢ Contact less between tag and reader. ➢ No reader inside the car. Use only tag ➢ No need to slow down the car. ➢ Tag and reader price is competitive to other solution due to elimination of the OBU inside the car ➢ Risk reduction of point miss reading

In addition the proposed system is also compared to existing tag collection system in Malaysia highway which is summarized in Table 5 below:

Table 5: Technical comparison of the proposed system to current system in Malaysia highway

Characteristics	**This work**	**Current toll collection system in Malaysia**
Technology	Uses active 5.8 GHz radio frequency communications with Zig Bee support.	Uses active infrared light communications.
Distance	On-board unit (OBU) vehicle based device used as an ETC system over long distance (200 m as standalone)	on-board unit (OBU) vehicle-based device used as an electronic toll collection (ETC) system over long distances (maximum 15 metres)
Miss identification on follow-on vehicles	No	No
Adaptability	Can read multiple data at a time. Simultaneously data reading capability.	Only read one data only at a time. Not capable to simultaneously read data.
Detects vehicle speeds	1600 tags/seconds	As fast as 40 milliseconds.
Lanes & barriers/gantry	No toll lanes / automatic barriers, use gantry system	Used at dedicated toll lanes with automatic barriers
Speed	Faster traveling speed / Utilization of current assets to reduce capital investment for MLFF	Reduced speed at SmartTAG lanes
OBU (On-board unit)	Two & Single piece on-board unit (OBU)	2 piece on-board unit (OBU)
Signal Area	• Localized within an area, not contained by walls • Signal can protrude walls or objects	• Localized in a closed area, contained by walls • Signal bounced with walls or objects
Vehicles Speed limit	Approximately 300km/h	40km/h

The proposed RFID system needs integration with image processing technologies in the future for car plate recognition system and vehicle type recognition system as illustrated by Figure 11. The car plate number is assigned to stored tag ID through database where the tag can only be used by the registered car plate number car. The camera is used for monitoring and recognizes invalid car entry and exit. In addition, it also differentiates different type of vehicle if the tag used and car plate number registered is matched with the record. The detection range can be as far as 5 km in a mesh network.

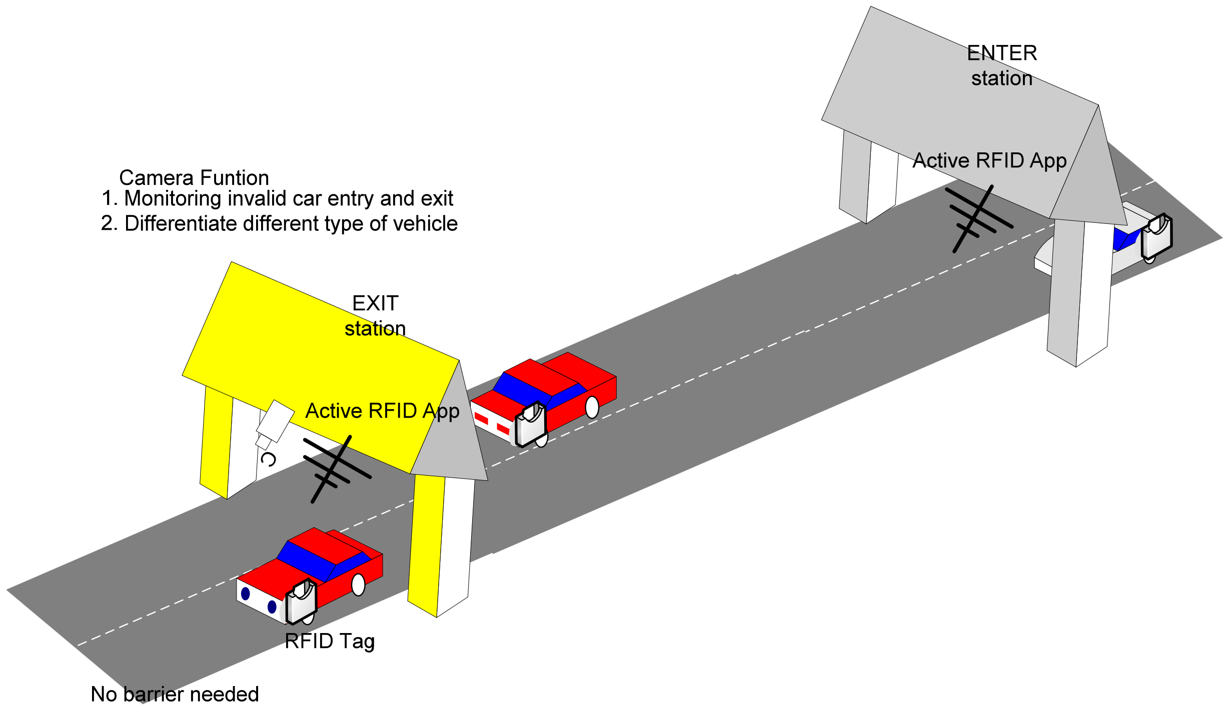
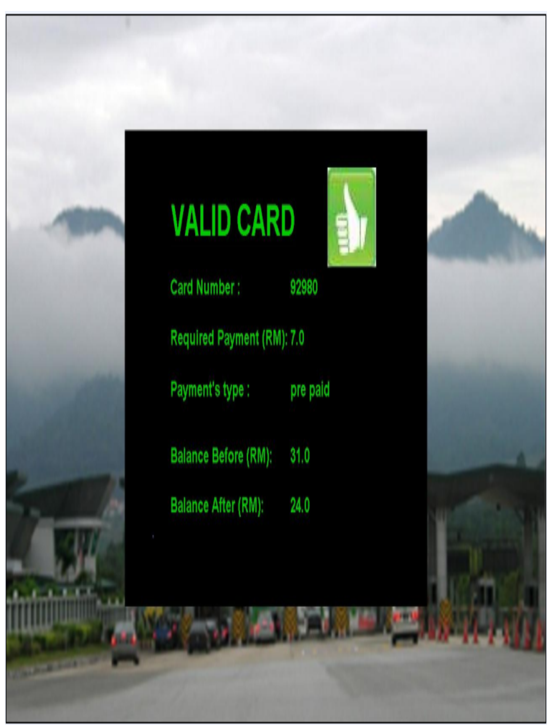
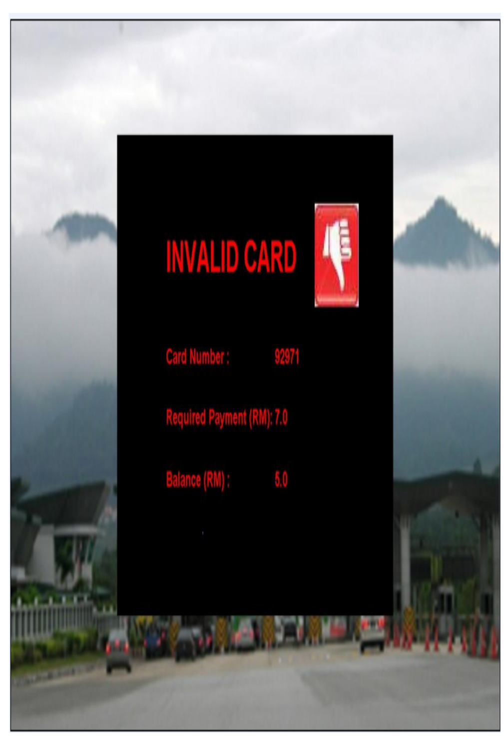


Figure 11: System setup on a highway

The proposed electronic payment system can be using prepaid card, credit card and postpaid card and as an example of the database, prepaid and record tracking of the GUI snapshot are shown in Figure 12 below.

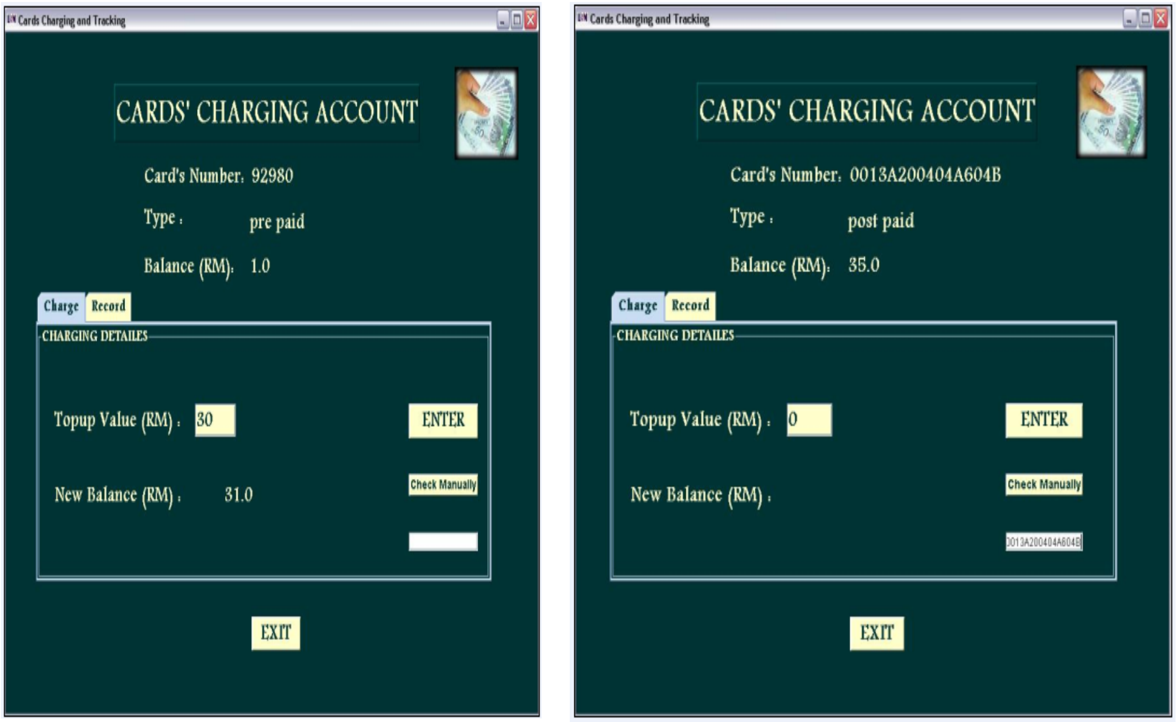


Valid Card

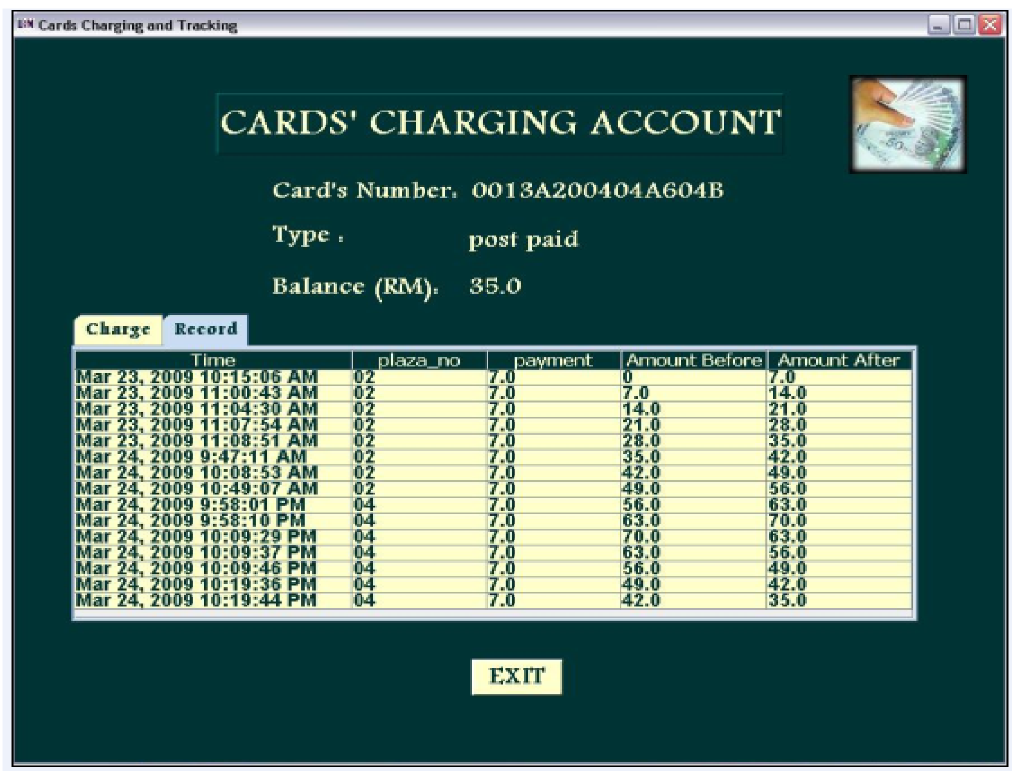


Invalid Card

(a) Prepaid



(b) Account to charge (Prepaid/Postpaid)



(c) Record Tracking

Figure 12: Developed GUI for ETC (a) Prepaid (b) Account to charge (Prepaid/Postpaid) (c) Record Tracking

5. Conclusion

In this paper, various technology for ETC and MLFF has been discussed. The proposed MLFF system proposed in this work applied 5.8 GHz active RFID system. The architecture of the RFID tag and reader has also been proposed. Some of the preliminary performance evaluation of the proposed 5.8 GHz active RFID system also has been presented. The results have shown the possibility of using the proposed 5.8 GHz RFID system in MLFF ETC system in Malaysia. With the elimination of the human intervention in the whole toll system, therefore better and efficient toll collection in Malaysia can be realized.

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