RFID-based Electronic Fare Toll Collection System for Multi-Lane Free Flow – A Case Study towards Malaysia Toll System Improvement

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***Abstract*—RFID-based Electronic Toll Collection (ETC) system for Multi-lane free flow (MLFF) is a system that enables collection of toll payments electronically using RFID tags, allowing for nonstop toll collection and free-flow of high-speed travelling at toll highway with use of ordinary multilane road segments and aim to eliminate toll plazas and booths. The system allows vehicles with passive RFID tag to emit communication with front-end reading system to uniquely identifying and classifying each vehicle and transfer the toll transaction back to a centralized back office system for revenue collection by deducting from the account of vehicle owner. The RFID-based ETC systems have been implemented in developed and developing countries like Turkey, Taiwan and countries of South America. The review is focused on the RFID-based ETC system architecture that has been implemented by some these countries. The review may help to understand how the overall system works hence it shall provide the essential information in migrating and re-engineering current toll booth ETC lane system to MLFF system and serve as a reference view of the system concept in developing a new RFID-Based ETC system for MLFF**

***Index Terms*—Multi-Lane Free Flow (MLFF); RFID-based Electronic Toll Collection (ETC) System; System Architecture.**

I. INTRODUCTION

With the increase of vehicles on the toll road in most of the cities around the world, the need to improve the toll payment system has been crucial. Subsequently an aim for improvement of electronic toll collection (ETC) system among toll highway network have been greatly undertaking by the tolling service providers, by implementing the RFID-based (ETC) system. The implementation intents to alleviate delays and remove traffic jam at toll collection points. This type of payment collection method would enable a smoother traffic at toll highways by facilitating automatic vehicle identification and electronic toll collection.

There are many types of ETC system for Multi-Lane Free Flow (MLFF) systems, also known as open road tolling (ORT) [1] or High Occupancy Toll (HOT) systems. The systems allow for free-flow of high-speed tolling at toll highway with the use of ordinary multilane road segments with the aim of eliminating toll plazas and booths from the highway. Highway users are no longer required to stop at toll lanes, nor even slow down when passing through for the reserved electronic payment lanes. The Passive RFID-Based ETC system is a system that uses passive RFID Tags that enables the collection of toll payments electronically, allowing for nonstop toll collection and traffic monitoring. The system has been positioned to reduce the traffic congestion, ease the demand for maximum throughput and high efficiency tolling services. It provides the double functions of collecting toll payment automatically and electronically, and increasing control for the operations and management by providing vehicle and traffic monitoring and data collection. There are many countries that have been implementing the RFID-Based ETC system for MLFF and among the developed and developing countries are like Japan, Taiwan, South Americas, Turkey, U.S, etc ([2] and [3]).

II. OVERVIEW OF RFID-BASED ETC SYSTEM ARCHITECTURE

The RFID-Based ETC for MLFF is an electronic toll collection without having toll plaza and booths setup at toll collection points [1]. The system allows for the vehicles that equipped with passive RFID tags to emit communication, with sensors at toll lanes and computerized system (include hardware and software) for uniquely identifying each vehicle ([1], [4], [5] and [6]). The system then defines whether the vehicle passing is registered within the toll payment system or attached with a valid RFID tag. If it is valid, it automatically deducts the account of registered vehicle owner at the centralized back-office system. For those users that with invalid tags, the system will trigger the enforcement system and alert the relevant enforcement team for the invalid transactions. Generally, the toll fare charging for the MLFF system is based on the distance travelled and charged to the road users based on each of toll gantry bypassed.

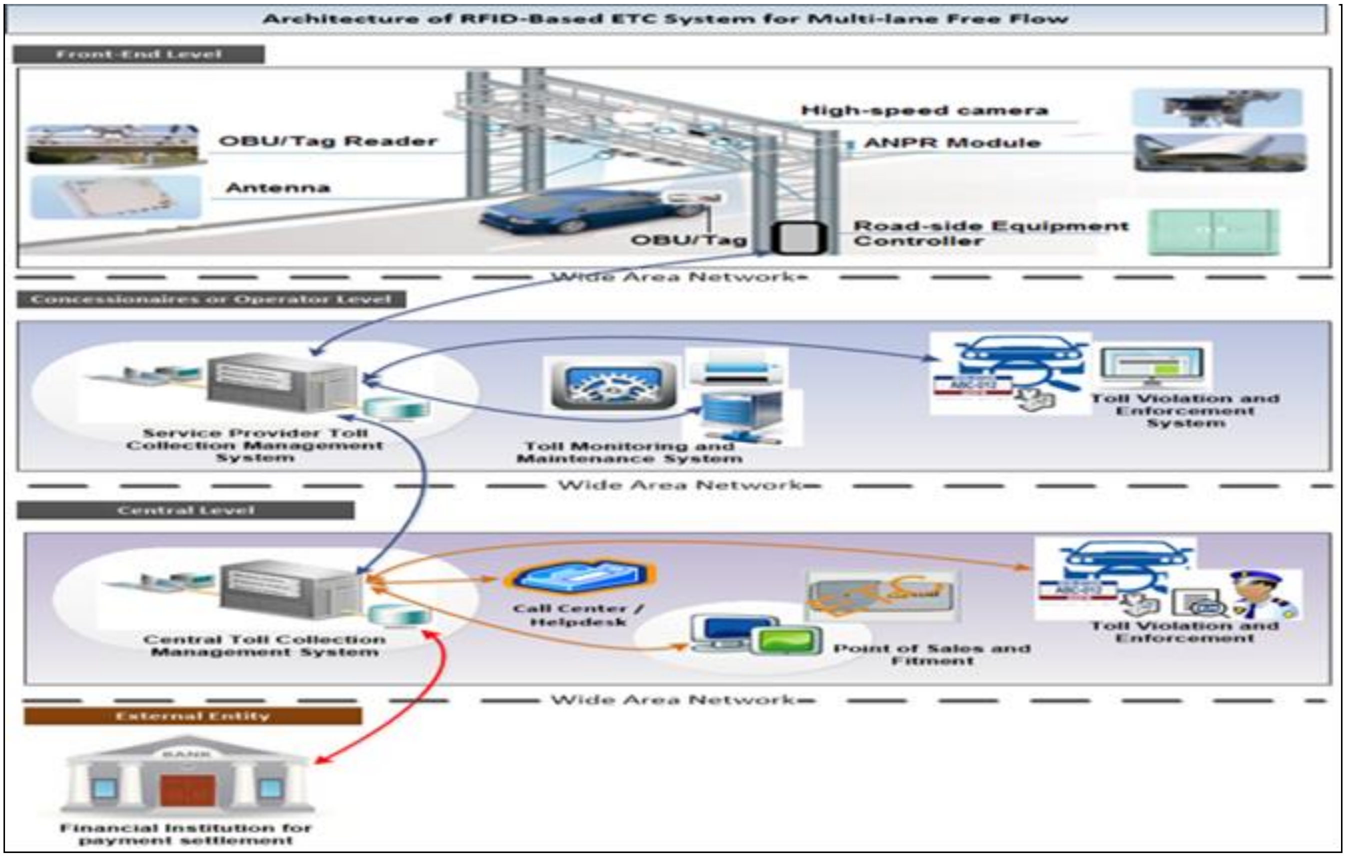

Figure 1: A general architecture of RFID-Based System for MLFF

A. System Functions

There are five major functions of the ETC system which include the Automatic Vehicle Identification (AVI), Toll Violation and Enforcement system (TVES), Automatic Vehicle Detection and Classification (AVDC), Service Operator Toll Collection Management system, and Central Toll Collection Management System for centralize management of all toll transactions ([7], [8] and [9]).

The Automatic Vehicle Identification (AVI) is a technique that identifies vehicles in toll collection zone by RFID tag that attached to windshield of a vehicle and communicating with the roadside transceiver installed on overhead structures such as highway gantry in order to determine the ownership of the vehicle ([10] and [11]). The unique identification of the RFID tag ensures that the corresponding vehicle owner is charged for the toll fare [11]. The automatic vehicle identification system creates a unique toll transaction for each vehicle and sends back the transaction to the central toll collection management system for further processing [10].

The Automatic Vehicle Detection and Classification (AVDC) is a method to detect and classify moving vehicles that determines the configuration of the vehicle according their categories for toll fare charging ([10] and [11]). The vehicles are categorized into classes for example cars, big or small buses, trucks, motorcycles and others, mainly to ensure that the toll fare is charged according to such classes ([11], [12]).

Toll Violation and Enforcement System (TVES) provides the function of capturing vehicle image and plate number that passed through the lanes with an invalid RFID tag ([10] and [11]). The high-speed camera captures license plate and image using the digital imaging techniques and sends to a central storage location. This feature of violation detection and enforcement is important for the success of an RFID-Based ETC system since all toll usage payments are made at the Central Toll Collection Management system [12]. Any violations must be processed and managed accordingly to ensure that no toll collection revenue leakage.

The Service Operator Toll Management Collection system provides toll transaction processing that generates operational and financial reporting for highway operators to reconcile with the central clearing house agency. The use of single payment media such as RFID tag with a single electronic account (e-wallet) across all highways, that allow the central clearing house agency to make payment to the operators after they have deducted the vehicle owner account for the toll charge based on the financial reporting [13].

The Central Toll Collection Management that act as central clearing house, is the principal function of any ETC system. It allows for transactions reconciliation, apportionment and clearing of payments among the toll operators registered by realizing their commercial agreements for interoperable electronic toll transactions usage across all highways [12]. Among other functions of the system include managing the vehicles' owner account, centralized RFID tags database to associate with the electronic account, provide a common action list that able to enhance services to customers and operators [13].

B. System Architecture

The overall system is described in a three layered architecture and these systems components provide the most critical functions required to successfully implement the MLFF system. In general, they are described in the Figure 2.1and these components are tightly integrated and connected to provide the major functions of the system ([5], [6], [9], [13], [14], [15] and [16]). These components are:

1. Central Level - This level consists of the Central Toll Collection Management System which it is managed by the central clearing house agency or government. The main function is to consolidate all the transaction from all highways and process them for reconciliation with highway operators ([12] and [13]). The system is also integrated with the financial institutions in order to collect payment from the vehicle owner and also made payment to the operators [17].
2. Operators Level - Usually, this level compose of Service Provider Toll Collection Management System, Toll Violation and Enforcement system, and Toll Monitoring and Maintenance System. All these subsystems are interconnected to ensure all information are updated. The system must be connected to the Central Toll Management system. This enables the system to receive real-time transactions and all violation can be managed accordingly and instantly by updating the vehicle owner account.
3. Front-end Level - This is the lowest level where all toll transactions are generated. This level consists of a few key components that are used to generate toll transaction, detect vehicle and violation, capture vehicle image and provide equipment health status. The main components are Vehicle Detection and Classification System (Automatic License Plate Recognition (ALPR) Module, Enforcement module and High-Speed Camera), Reader (Controller, Antenna), MLFF Gantry, Road-side Controller and integration module with Service Operator Toll Collection Management System.

III. PASSIVE RFID-BASED ETC SYSTEM IMPLEMENTED

The system for MLFF implementations are different from one country or even one toll road to another in the same local state or country. The principles for the system implementation are always founded on the local context and users requirements. Some of the countries that have implemented the passive RFID-Based ETC system for MLFF are discussed in the proceeding section.

A. Brazil

In Brazil, they started the Brazil ID using passive RFID Tag for their transportation industry as the tag is affordable by the public [18]. The ID are being used for the RFID-Based ETC System for MLFF that was first implemented in year 2013 in the Sao Paulo state which include 19 Highway Operators of the Sao Paulo Transportation Agency (ARTESP) [19]. The system allows multiple Service Operators working independently but using the same RFID tag and have the same system infrastructure (the Front-end reading system with integrated Central Toll Management System) to serve all the qualified operators [18]. It also integrates with all other aspects of vehicle identification, classification and violation systems [20]. The overall system architecture of Sao Paulo RFID-Based ETC System is described in the Figure 2.

The Central Toll Management System is managed by the government. The operators are using middleware system that integrated with multiple frond-end reading systems and connected to the system [18]. The Central Toll Management System provides support to all the infrastructure companies that coordinating the integration and operation at all levels from the RFID tags and readers to the IT systems for the Operators and Government [19]. The systems integrated into one interoperable system with more than 10 million toll transactions each month and still growing [19].

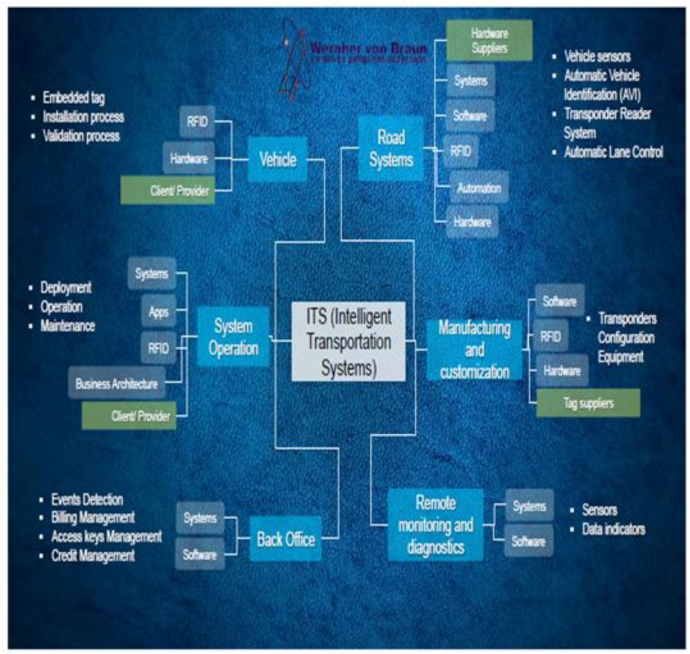

Figure 2: The overall system architecture of Sao Paulo RFID-Based ETC System [20]

B. Taiwan

The Taiwan National Freeway Bureau (TANFB) has implemented the passive RFID-based ETC system in year 2012 [21]. With the high penetration, the TANFB has introduced distance-based for multi-lane free flow (MLFF) scheme with 319 gantries to the road users in December 2013 with about average of 14 million transactions daily ([21] and [22]). The front-end system combines the equipment on single gantry: the RFID reading system using the open 6C standard technology, Enforcement and Violation System with ALPR and Audit system [21]. Taiwan's ETC system for MLFF also supports road pricing that uses various charging models that based on toll zones, transaction time, trip distances and a combination of all ([21] and [22]).

The above systems are connected to the Service Operators Toll Management System that connected to the Central Toll Management System and it is managed by the Government [23]. The overall system architecture is described in the Figure 3. Taiwan's system also includes Electronic Road Pricing (ERP) System, Smart Parking Toll System, Real Origin-Destination Matrix Collection (Traffic Data Collection)

System, Traffic Reporting and Route Guidance System, etc ([21] and [22]).

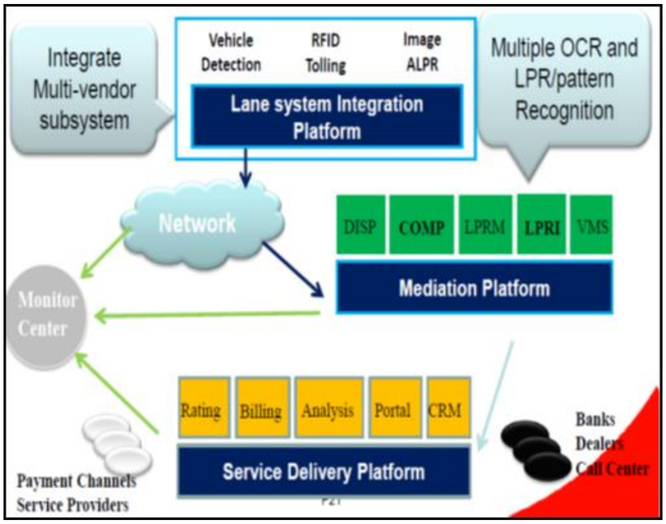

Figure 3: Taiwan's Overall RFID-Based ETC System Architecture for MLFF [13]

C. Turkey

Turkey has implemented the passive RFID-Based ETC system for its 2000 km national highway network and their ORT has been in Europe since 2012 with about 11 million users ([24] and [25]). The system is called 'Fast Passing System' (Hızlı Geçiş Sistemi - HGS) that was upgraded from the current Automatic Passing System (Otomatik Gecis Sistemi - OGS) technology [24]. The system is integrated with an electronic central back-office payment system for a robust infrastructure of vehicle validation and enforcement. The HGS system uses license plate recognition cameras for enforcement. For vehicle that uses an invalid tag, the system will detect the defaulter and penalty will be applied [25]. The system is connected to the Central Toll Management system that has a real-time calculation and transmission of the toll transaction data [25]. The operator's back-end office system consists of seven regional computer centers and a central server that connecting through the fiber-optic cable and satellite network ([24] and [25]). The modular Central Toll Management system architecture also comprises of violation and enforcement system, integration with banking system, and able to integrate with other types of toll collection or payment services [24].

IV. Comparison

Comparing the architecture of the three countries mentioned above, they are each having a slight different of the system architecture. For Taiwan, they have only two highways that interconnected and both are managed by a single highway concessionaire (the Taiwan's government). They are funding all the highway implementation cost and control the operations and revenue collections. Therefore, the implementation of the system is easier whereby all the systems of toll revenue and collection. The toll legal and operational policies are easily implemented by the government to ensure that everyone pay the toll fare. They are having three levels of architecture, the front-end system, Service Operators Toll Management System and Central Toll Management System. For the Brazilian, the government is managing their Central Toll System but allow multiple Toll Service Operators to work independently by using the same RFID system and have the same front-end reading system with integrated to the Central Toll System. They also have three layered architecture whereby from front-end system to the middleware system that managed by the operators and to the Central Toll System. However, the middleware system is developed and implemented by the Toll Operators themselves. For the Turkey highways, they have seven regional toll systems connected to the centralized toll back end system and operated by single operator that managed by system provider who provides end to end solution from front-end to centralized back-end systems. They implemented a three layered architecture, the front-end system, regional system and centralized back end system that well connected to each other.

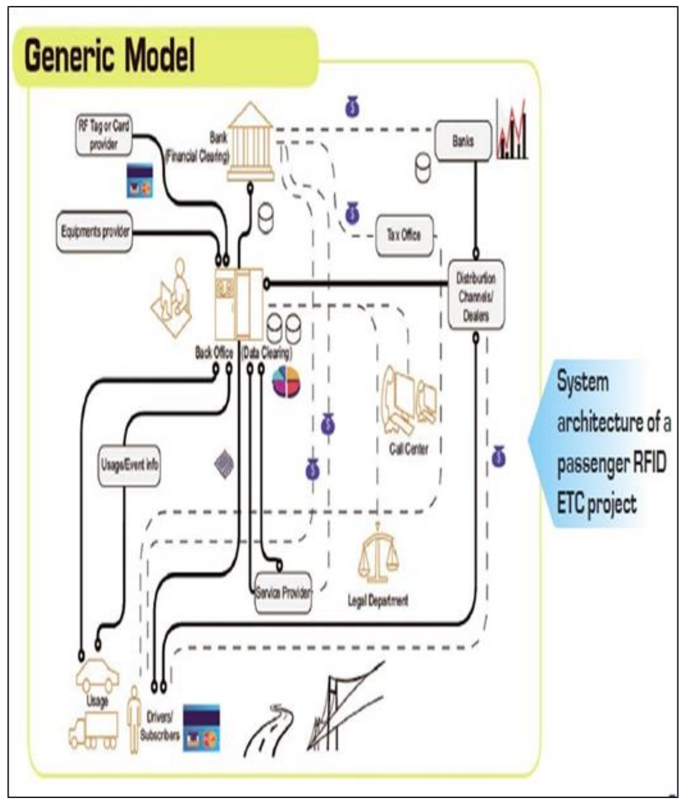

Figure 4: The overall system architecture of HGS system for Turkey's RFID-Based ETC System [26]

In the context of Malaysia toll highway systems, there are a few differences with the above mentioned system architecture, since currently there are 38 toll highways with each individual operator that operate the highway and these highways are owned by 29 concessionaires that manage these operators and own the highways. For current ETC system, they are using SmartTag (on Board Unit with smart card). Each concessionaire is having their own individual toll collection system that connected to the Central Toll Management system (managed by Touch N Go). These toll systems are also connected to the Malaysian Highway Authority (MHA) system that manages the toll information system. Therefore, in order to implement the new RFID-Based ETC system, the system architecture will be different as compared to system mentioned. It needs to cater for all the stakeholders' needs and current operational structure of the toll highways systems. The Table 1, summarizes the system architecture implemented by the countries. The advantage sand disadvantages of the RFID-Based ETC system and current system implemented in Malaysia is described in the Table 2.

Table 1
Summary of systems implementation and architectures by country

Country	Implementation Year	Highway (Owner)	Highway Operator	Current ETC System	System Architecture (Layered)
Turkey	2012	Government	System Provider	Passive RFID	Three levels (Lane system, Regional system, Central Toll system)
Brazil	2013	Government	Toll Service Provider	Passive RFID	Three Levels (Lane system, Middleware system, Central Toll system)
Taiwan	2013	Government	Toll Service Provider	Passive RFID	Three Levels (Lane system , Operator Mgmt. system, Central Toll system)
Malaysia	1997	Concessionaire	Toll Service Provider	Infrared On-Board Unit (OBU) with Smart Card	Five Levels (Lane system, Plaza System, Regional system, HQ system, Central Toll system)

Table 2
The advantages and disadvantages of the RFID-Based ETC system and current ETC system in Malaysia

RFID-Based ETC System for MLFF	
Advantages	**Disadvantages**
<u>Road User</u> ▪ Obtain toll usage and account information in real time/online ▪ Smooth travelling at highway due to no queue and no toll booth ▪ Time and fuel saving ▪ Cheaper passive RFID tag <u>Highway Operator</u> ▪ No implementation cost for toll booth and plaza ▪ Reduce operational and maintenance cost due to less hardware and no toll teller ▪ Easy to implement road price charging ▪ Easy to add new toll interchange <u>Highway Authority /Government</u> ▪ Easy access on toll information ▪ Easy to conduct audit activities ▪ Easy to add new highway and toll operator	<u>Road User</u> ▪ Must have bank account ▪ A tag is dedicated for a respective vehicle <u>Highway Operator / Authority / Government</u> ▪ Revenue leakage due to violations (the toll fare is deducted from user account) ▪ Require investment for the new system implementation ▪ Require a good enforcement system and legal framework to endure payment is made by road users
Current ETC system in Malaysia	
Advantages	**Disadvantages**
<u>Road User</u> ▪ No need to have bank account ▪ The OBU can be transferred to other vehicle <u>Highway Operator / Authority /Government</u> ▪ Minimal revenue leakage because user need to reload the smart card ▪ Easy to manage violations with toll lane barrier ▪ Easy to implement enforcement system	<u>Road User</u> ▪ Queue at toll booth due to lane barrier ▪ Uneconomical due to queuing at toll lane that uses more fuel ▪ Need to reload account at counter / terminal ▪ Expensive OBU unit <u>Highway Operator</u> ▪ More implementation cost needed for toll booth and plaza ▪ More operational and maintenance cost due to more hardware and toll operational staff required at toll plaza and lane ▪ Could not implement road price charging ▪ Difficult to add new toll interchange <u>Highway Authority</u> ▪ Difficult to access toll information ▪ Difficult to conduct audit activities ▪ Difficult to add new highway and toll operator

V. CONCLUSION

In summary, the implementation of a new RFID-Based ETC system for MLFF is normally based on the efficient and economical combination of the RFID tag on board vehicle for users. Also include the dynamic vehicle detection and classification, video capturing and processing for violation and enforcement to perform toll transactions. A complete solution should also comprise of a detail planning and design of centralized system for toll collection and settlement, payment channels, acquisition and distribution of RFID tags, roadside tolling infrastructure, network communication, violation and enforcement processing for any non-compliance cases. Thus the total costs for each solution will vary based on contextual of each country and local situation and needs. The maturity, reliability and costs of the system also acceptance by stakeholders is among the most fundamental drivers in the decision-making process of adopting the system for MLFF. The implementation is also influenced and guided by an evaluation to setup a centralized electronic account (e-wallet) of tolling system and establishment of centralized violation, enforcement and legal framework. Other consideration includes a detailed analysis of the costs and benefits, business case objectives, tolling and charging policy, highway network topology and the context and goals of the local highway and transportation authorities.

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