# A MOBILE ELECTRONIC TOLL COLLECTION

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Abstract: When mobile communication has been vastly used, its particular characteristic is appreciated for the idea of mobile e-commerce (Me-commerce) in any electronic toll collection (ETC) applications. This paper establishes a new method of ETC using mobile cell phones integrating mobile communication with radio frequency (RF) communication adopting microprocessor control. A simple ETC system architecture and protocol for transactions among vehicles to toll stations to complete payment is presented. The proposed ETC contains e-transaction mechanism in hardware and software. A software flow through Internet is developed to link from toll station roadside units to car units. A car unit for vehicle, a pair of roadside units, and an e-Center are established. Data flow and interaction protocol are created. The proposed ETC system can be applied to toll different systems on freeways, bridges, parking lots for un-manned operation. The proposed system is designed with hardware circuit using microprocessors to match with software system. The preliminary test results on system performance verifies as a good solution for ETC applications. Some feasibility analysis is made with test support. The function capability for Me-commerce is also demonstrated.

## 1 INTRODUCTION

Mobile communication has become a livelihood technology to be widely adopted. Back to 2002, the mobile communication users have already overwhelmed the vehicle users in most developing and developed countries. While e-commerce is introduced to elevate daily commercial interactions from the conventional concept, mobile e-commerce (Me-commerce) is another trend to be considered and a more popular topic in wider discussion. Me-commerce is defined as a commerce trade by mobile stations (Mueller-Veerese, 2000) (Tarasewich et al., 2000). Mobile stations include wireless phone, wireless handheld computer, laptop, personal message pager device and personal digital assistants (PDA) (Christoffer, 2001) (B. V. Education, 2000). Me-commerce presents the function of personal mobility, operational flexibility, and interactive capability. Due to the high population of mobile communication users, Me-commerce is a rising demands to the public in the next decade.

Focusing on the development of Intelligent Transportation Systems (ITS), road information acquisition and data processing to road users are the most important role of study. In China, road construction and personal vehicle are two vast expansions in the world. Toll collection is mostly adopted to share the investments. How to carry out efficient toll collection is most concerned. Technologies on all different demands are studied and designed to fit the requirements. Among them, unmanned toll collection is one of the urgent problems to solve in many places. Methods for toll collection have been developed since 1980's including microwave system, optical system and recent RFID system. Some technologies are quite mature in real world implementation.

Since mobile communication has been accepted as a popular livelihood handy device around the world and in China, its mobility characteristics are merited for extensive personal use. Especially in China, most personal vehicle users (or around 99.9%) use mobile phones. The combination of mobile communication with toll collection is a useful idea to toll center, road users, and system providers to become a new added value application.

For toll collection, the e-transaction needs to be



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established in conjunction with finance corporations or banks. A survey shows that different countries providers different strategies in offering the e-transactions under Me-commerce system. In China, bank system accepts e-transaction through mobile system providers. However in Taiwan, the bad debts or irrecoverable credits from mobile bills are huge burden to them. However, the finance corporations or banks, who issue credit cards, would appreciate the new Me-commerce based on the contracts. Under such circumstances, Me-commerce for ETC using the proposed mechanism will become viable. An Internet linkage e-interaction system should be created in the proposed ETC system.

For most methods for e-commerce and Me-commerce, there are demands of matching hardware and software to meet the system requirements for user identification, function recognition, interaction authentication, data storage and processing. A complete system design should include software and hardware solutions to realize the proposed system concept.

For personal mobility, any kind of wireless communication can be considered. Radio frequency communication has been used for several decades. VHF data link (VDL) is developed as an important media for long range data communication. Its system infrastructure, operation and maintenance are tedious and expensive engineering work but poor coverage from ground users. Wireless communication based on 802.11, blue tooth, RF and others may be capable for excellent performance for high data rate, but are limited in transmission range. The wireless technologies are known as 100 meters or less. The extension of communication coverage requires a complete plan of networking, such as mobile base stations. For consideration of limit distance short message interaction, wireless communication can be adopted. Another problem might be considered on the population of users. The frequency division multiple access (FDMA) technology has its defect to occupy frequency channel by each user. The time division multiple access (TDMA) and code division multiple access (CDMA) overcome these defects to use frames and slots for each packet data. All users will not occupy certain frequency channels, and will share the quality of service in use. Mobile communications, of the second generation (2G) of Global System of Mobile communication (GSM), the 2.5 G of General Packet Radio Service (GPRS), the 3 G of wide band communication, and beyond 3G (B3G) of higher performance system, are introduced (Jorg, 2001) (Joachim, 2001). Base stations for wider coverage of excellent infrastructure investment have been well furnished in most developing and developed countries (Gunnar, 1998). The adoption of any mobile communication service will be a correct choice in the future development. Beyond wide range coverage, short distance data exchange using wireless communication can be considered as integration into a new system design.

This paper proposes a feasible solution of ETC using mobile communication infrastructure to achieve toll collection as part of Me-commerce. The proposed ETC protocol is organized by GSM, RF module, microprocessor (AT89C52) and the related hardware for circuit design and implementation. The proposed ETC contains car unit (CU) and road side units (RSU) to exchange the toll message between vehicle and toll center. A toll protocol is studied and established to fast complete a toll transaction within driving through period. By on-campus test, the proposed ETC is verified with feasibility in GSM framework (Jorg, 2001) (Joachim, 2001) (Gunnar, 1998).

In this paper, system installation is designed and fabricated out in the laboratory with complete on-campus experiment. Technologies such as Car Unit (CU) and Road Side Unit (RSU) using microprocessor to exchange message between RF transceivers are involved. The communication means of RF and GSM in hierarchical structure is organized to link a transaction and authentication process with software implementation.

## 2 SYSTEM FRAMEWORK

In this paper, we propose a new ETC system design using mobile communication for freeway and parking lot application. The proposed ETC system configuration is shown in Figures 1, 2 and 3 for different applications as solutions for freeway entrance gate control, toll station control and parking lot control. In the proposed ETC system, there are key components to develop, such as the Roadside Transmitter (RS-TX), the Roadside Receiver (RS-RX) and the Car Unit (CU). In the proposed ETC system design, both systemic hardware as well as Me-commerce software is discussed in details.

The CU includes a group of the identical electronic transceivers as RS-TX and RS-RX, termed functionally as CU-TX and CU-RX, respectively, using a microprocessor for digital signal processing. It is a device on the vehicle. The functions of

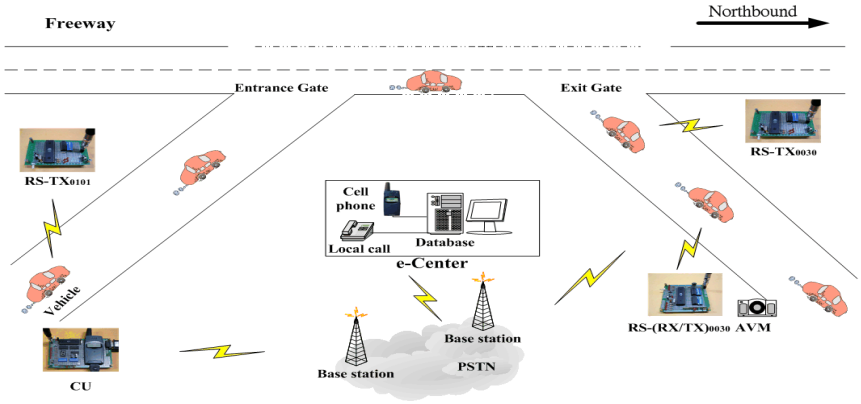


Figure 1: Architecture of ETC System for freeway entrance gate control.

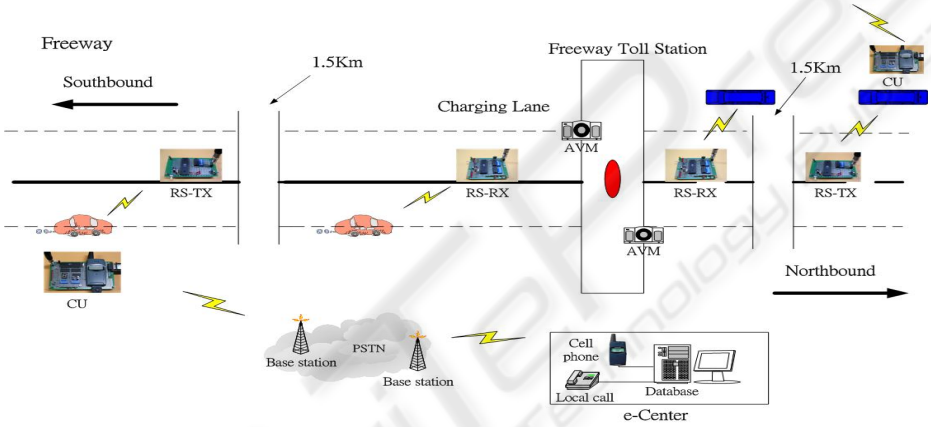


Figure 2: Architecture of ETC System for freeway toll station control.

CU-TX and CU-RX in the Car Unit will transmit and receive message from the Roadside units. The Roadside Transceiver (RS-TX) will transmit an interrogation message to active the Car Unit to start the GSM handset for ETC electronic transaction as a part of Me-commerce. While the Toll Center accepts the M-transaction, the GSM handset will receive an approve code for the Car Unit. The Car Unit will acknowledge to Roadside Unit at appropriate instant of passing-by the Roadside Receiver (RS-RX) to complete the acknowledgement. The Roadside units are connecting to the e-Center via wired or wireless technology into Internet. GPRS onto Internet will be a good means to adopt (Joachim, 2001).

In Figures 1 to 3, three different applications will result in three different ways of Me-commerce transaction. In this paper, GSM system handset is generally considered as personal ID code to verify the Me-commerce of ETC. We use Microsoft 2000, VB 6.0 and Microsoft Access to simulate the message exchange among CU, RS-TX and RS-RX under different considerations.

In reality, we choose the hardware that is suitable for conditions of this paper. The CU, RS-RX and RS-TX architecture are shown in Fig. 4 in general configuration. Circuit parts may be selected for either CU, RS-TX or RS-RX. We choose AT89C52 to handle communication and computation in the CU, RS-RX and RS-TX. The HT-12E is encoding the signal data in CU-TX and RS-TX for transmission. The HT-12D is decoding the signal data in CU-RX and RS-RX. The HT-12E and HT-12D have 8 address bits and 4 data bits to be used. The RS-232 port is the communication interface that is cell phone and AT89C52 (Carr, 1993). AT89C52 can command cell phone by RS-232 port. In the hardware implementation, we build the CU, RS-TX and RS-RX according to the hardware designs as discussed previously (AT Command Set of SIEMENS MC3.'5). ETC system

hardware is installed and integrated for test as shown below diagrams of Figures 5~7, correspondingly.

Evaluating from the circuit hardware, the overall cost for road side units (RS-TX, RS-TX) and card units (CU) are fairly cheap to implementation.

We will discuss the flow of experiment and test and verify in the next section. The test circuit has been completed and ready for tests. All circuits are built in breadboards that make easy for changes and modifications during tests.

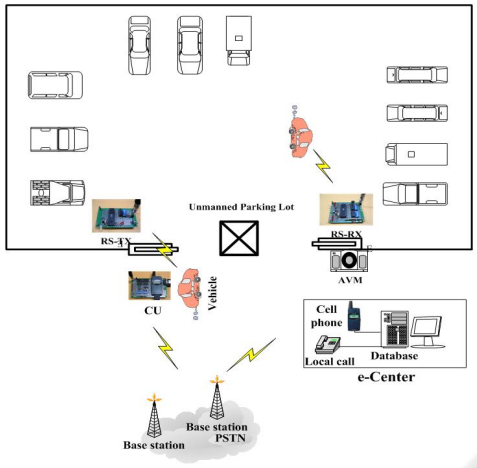


Figure 3: Architecture of ETC System for parking lot.

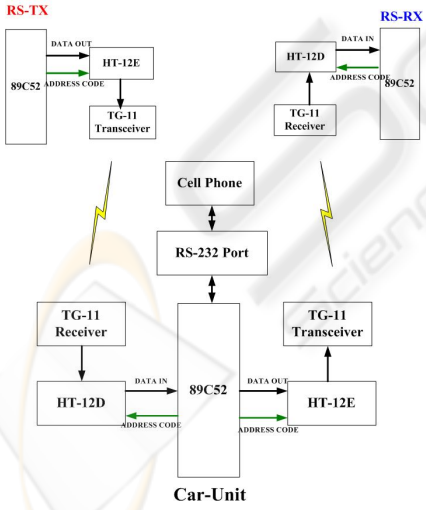


Figure 4: Architecture of CU, RS-RX, RS-TX.

# 3 APPLICATION OF SYSTEM

From different ETC system configurations as shown in Figures1~3, the ETC System for freeway entrance gate control will be described in the following section as shown in the Fig. 1.

## 3.1 Concept for Development

In Taiwan, the toll system will be converted from toll station control into entrance gate control. In China, gate entrance control is most adopted on most freeways. In European countries, wither toll station controls or gate entrance controls are applied. Comparing the entrance gate control to toll station control, the toll collection process might be simplified the process and enhance efficiency. In the proposed ETC, there is a Toll Collection e-Center to be a server to accept toll payment through Me-commerce system via mobile communication in transmission control protocol in addressed IP (TCP/IP) or point-to-point protocol (PPP). The will process the authentication, charge, and record in software and database.

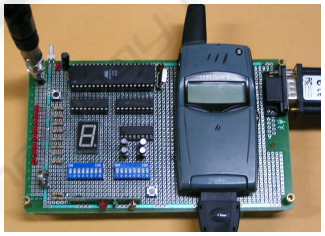

Figure 5: Hardware circuit of CU.

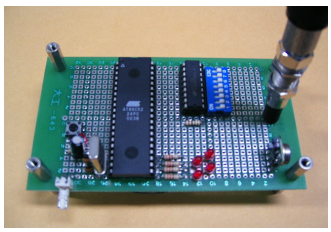

Figure 6: Hardware circuit of RS-TX.

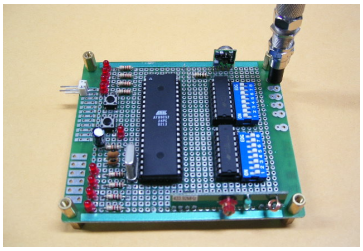

Figure 7: Hardware circuit of RS-RX.

## 3.2 Definition of Basic Protocol

There are about sixty entrance gates of along the freeways from north to south in Taiwan. Every flow control gate includes two directions with entrance and exit gates. We establish a set of roadside unit at each direction of every entrance/exit gate and assign code number for every entrance/exit gate. The Roadside Transmitter, RS-TX0101 is establishing in the entrance gate in the Fig. 1. The 0101 number code is an example of the entrance gate. The meaning of the first bit is direction bound, where 0 for the direction of northbound and 1 for the direction of southbound. Gate numbering starts from north to south. That means all southbound vehicles will enter from smaller number of control gates to larger number control gate to exit, and vice versa. The second and third bits represent the number of the flow control gate, where the tenth gate from north is used as example. The least bit stands for entrance or exit to this flow control gate, where 1 for entrance gate and 0 for exit gate.

In principle, since the northbound vehicles will not leave the freeway at any southbound gates, therefore, vehicles register from Gate 0101 should possibly leave from Gate 0080, which means 0 northbound, at Gate 08, to 0 exit, by the four digit assignment. Another example, the southbound vehicle enters at Gate 1101 may possibly to exit at Gate 1120. The toll charge will count the traveling distance between the entrance and thee exit. The former example northbound from 10 to 08, while the other southbound from 10 to 12. Fare basis can be determined from the Freeway Bureau in future realization.

In the proposed ETC concept, there will be a large number of installations for roadside units, and the car units. Cost for each unit will be concerned, as will the overall operation system.

## 3.3 Example of Freeway Entrance/Exit Gate Control

The proposed ETC system is organizing procedures in software to match with the hardware implementation for tests. The procedures have entrance to freeway and Exit from Freeway as shown in Fig. 1. The roadside units are installed on the entrance or exit ramps.

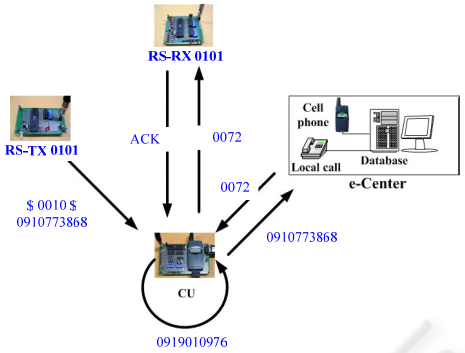


Figure 8: Procedures of entrance to freeway.

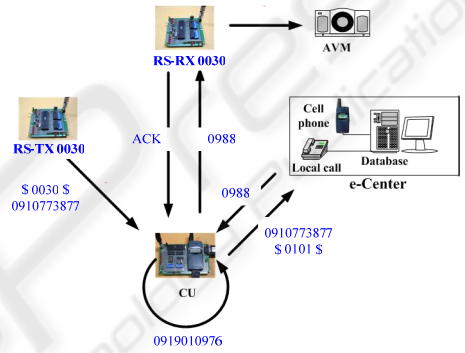


Figure 9: Procedures of exit from Freeway.

**A. Entrance to Freeway**

Fig.8 shows the procedure of vehicle from entrance gate onto freeway with the following steps.

(1) Step 1: The RS-TX0101 is operating on an interrogation mode to transmit a set code of 0101 and e-Center phone number at the entrance gate to the vehicles enter freeway. The RS-TX should be located near the intersection of thee local way and the entrance access road with an antenna to focus on small areas. The "0101" is designated as the address code of this particular entrance gate. When the vehicle enters the freeway entrance access, the CU will receive the 0101 code and the designated e-Center phone number from CU-RX. The LED display on CU will turn from orange to red. Note, each entrance or exit gates will be assigned with different phone numbers to link with the e-Center. The gate code 1010 will direct to its database assignment.

(2) Step 2: When the CU receives the 0101 code and e-Center phone number (0910773868)

from RS-TX0101, the CU will activate the GSM cell phone to dial up to register a toll collection.

(3) Step 3: The Toll Collection e-Center is always on-line to receive a call. When the mobile phone is connected, the e-Center will immediately aware of the cell phone number by on-call display (0919101976), the CU will send the RS-TX0101 code to the e-Center. The e-Center will store the registration data into database. Then the e-Center will bounce back an approval code (APC) 0072 to the CU. The entrance gate code 0101 and the approved code 0072 are memory into microprocessor AT89C52. This is the simple procedure of entrance registration. Approval code is a sequential number generating from each gate control processor for 4 digits. Approval code may possibly overlap within one day, however the marking time is different to identify.

(4) Step 4: The CU will send out the approval code on interrogation mode to RS-RX to acknowledge. The front panel will have red display turn to green for any visual inspection. The vehicle entrance to freeway is successful. The CU will write the data into memory as shown in Table 1.

(5) Step 5: The vehicle will proceed on freeway and the green LED will vanish to switch to orange. The data of 20 bytes to record date (ddmmyy), time (hhmmss), entrance gate code 0101 and approval code 0027 will be stored in the memory. The e-Center will write this data into 1010 database memory as shown in Table 2. Each database is assigned with is gate code. This reduces the database memory size and makes easy to search while the vehicle is existing from another gate.

**B. Exit from Freeway**

Fig.9 shows the procedures of vehicle to exit from freeway with the following steps.

(1) Step one: When the vehicle approaches the exit lane the freeway, the CU will receive the interrogation 0030 code and a new e-Center phone number from RS-TX0030 near the exit. The orange LED on CU will turn to red.

(2) Step two: The CU activate the cell phone to connect to the new e-Center phone number (0910773877), and send code 0101 to specify where the vehicle enters.

(3) Step three: The e-Center receives CU with user's phone (by on-call display) and the entrance gate 0101. The software will start trace onto 0101 database to find and match the vehicle using cell phone number 0919101976. The e-Center approves the toll collection from e-transaction and reply with a new approval code (APC) 0988 to the CU.

(4) Step four: The CU gets the new approval code 0988 from its cell phone and memory at the microprocessor AT89C52. The new approval code 0988 will be interrogated from CU-TX during exit to the roadside unit RS-RX0300.

(5) Step five: The RS-RX 0030 receives the interrogation 0988 and acknowledges to CU to turn on its LED from red to green. The vehicle will proceed to leave onto local highway, the data of 20 bytes to record date (ddmmyy), time (hhmmss), exit gate code 0030 and approval code 0988 will be stored in the memory. The CU memory is a read only memory (EEROM) by a auto-write process and a manual-clear process. A USB interface is used in the CU to exchange memory data from external devices, such as PDA or USB memory, to send out the record. The CU memory of 512 kB will maintain at least 6400 travel data. Table 1 shows the memory at car unit to memorize all travel data at 512 kB memory size.

(6) Step six: When the vehicle finishes the e-transaction, the e-Center will shift the memory data to the ETC Billing System to create a charge list to the bank. The ETC billing software will calculate the toll charge according to the traveling distance and fare. The fare is dependent if discount may apply.

Table 1: Memory at CU microprocessor for this test.

| Memory at Vehicle *0919010976* | | | |
|---|---|---|---|
| Gate | Code | Date | Time |
| *0101* | *0072* | *020604* | *134648* |
| *0030* | *0988* | *020604* | *151341* |

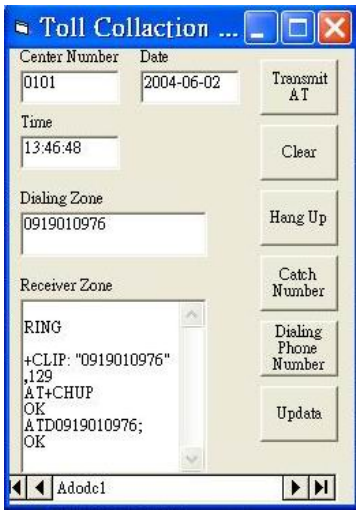


Figure 10: Display of 0919101976 at entrance gate 0101 processor.

## 3.4 e-Center Authentication

We establish a virtual e-Center to handle each entrance gate and exit gate. A Tabletop PC is used to simulate the e-Center. On the campus, we built a simulation drive way to set up Entrance gate 0101 and exit gate 0030 using roadside units RS-TX and RS-RX and Fig. 6 and Fig. 7. Two car units CU are built for two vehicles of 0919010976 and 0958890720. The Fig. 10 shows the display of two vehicles at the entrance gate 0101 and exit gate 0030 in e-Centers. In our simulation, the e-Center is connection to each gate unit by two GPRS phones (0910773868, 0910773877) through Internet as an wireless interconnection. We connect the e–Center to collect the CU phone number calling from the vehicle. The e-Center sends the AT+CLIP=1 of AT command for cell phone to enable the function to read the on-call display to identify the sender phone number 0919101976 and 0958890720. The CU phone number will be transmitted into the database built by VB 6.0 programs as Fig. 10. The CU cell phone may hang up at receiving the approval code 0072.

The ETC system will collect data from entrance 0101 and exit 0030 at e-Center to each relative database. Table 2 shows the designated database for Gate 0101 and Gate 0030 at e-Centers. Each phone number stands for a vehicle with a set of record to travel on the freeway. The ETC billing system can pick the first one on Gate 0101 and the first one on Gate 0030 to calculate the travel distance and charge. By the same way for vehicle user 0958890720, the charge can be calculated. The mechanism to adopt gate code as the database can reduce the overall size of the memory that search for a vehicle data appears will prompt. While the vehicle exits the freeway, the data on Table 2 will be moved to the Billing database at the e-Center. The memory data on each gate database are only very small part of vehicles running on the freeway.

Table 2: Database at e-Center for Gate 0101 and Gate 0030.

| Database for **Gate 0101** | | | |
|---|---|---|---|
| APC code | User | Date (ddmmyy) | Time (hhmmss) |
| *0072* | *0919010976* | *020604* | *134648* |
| 0073 | 0932977345 | 020604 | 135052 |
| 0074 | 0929771991 | 020604 | 135321 |
| *0075* | *0958890720* | *020604* | *135701* |
| | | | |

| Database for **Gate 0030** | | | |
|---|---|---|---|
| APC | User | Date (ddmmyy) | Time (hhmmss) |
| *0988* | *0919010976* | *020604* | *151341* |
| 0989 | 0933751685 | 020604 | 151522 |
| 0990 | 0915872561 | 020604 | 152233 |
| *0991* | *0958890720* | *020604* | *153400* |
| | | | |

The CU is offered by the credit card banks or the system providers when the cell phone users apply for ETC application. There is one possibility that the vehicle driver uses different cell phone that is not the one originally registered. An alternative may be created from the EEROM to input the claimed cell phones to be used. When the CU is connecting to a cell phone, the EEROM will check the cell phone. This is a necessary if payment authentication. In this proposal, the ETC charge will be placed onto the mobile phone bills.

# 4 TEST AND VERIFICATION

The proposed mobile ETC system has been implemented in hardware and software for tests on campus. There are some significant data being collected from the tests.

(1) The RF transmission range for RS-TX, RS-RX, CU is tested up to 50 meters for a speed of 40 km/hour, which is the post speed limit on the freeway ramps.

(2) The GSM connection time from receiving the RS-TX interrogation is 5 to 12 seconds,

with the most population falls at 7 seconds. The normal travel distance for a vehicle at the ramp is from 55 to 133 meters, or most population at 77 meters. Typical ramp distance is much longer than 300 meters.

(3) The CU processes the reply interrogation to RS-RX takes 10 milli seconds, and then writes the approval code and time into EEROM.

(4) In our tests, the roadside units are connecting with GPRS modules to link with e-Center through Internet, that no additional engineering work for wiring is necessary.

(5) At the exit, when the vehicle connects to Gate 0030 database, the search time from 0101 database takes only a few mili seconds on 200 simulation data. The traveling distance at the exit ramp is much longer than the entrance. However, the GSM connection time is still enough for this process.

(6) The GSM charge for two connections is calculated less than 6 seconds, which means NT$ 1 for this travel using mobile ETC. There can be discount plan to offer attractive fare to the users, or the system providers to absorb assign all gate control phones in free charge. In Taiwan, 5% discount is applied for mass users, or typically from NT$ 2 for very short travel to NT$ 20 for a long travel.

# 5 CONCLUSION

The proposed mobile electronic toll collection system is verified from hardware fabrication and implementation with a simulation test on campus. The test data show that the proposed technique is useful to create a new concept of mobile e-commerce to enhance the mobile phone users. From point of view of the freeway operators, the banks or the system providers, the proposed mobile ETC will reduce some labor work to shift to discount plans. Considering the created technology in this paper, the roadside units are much less than any investments on ETC projects. The necessary car unit (CU) is estimated for about NT$ 400 (or RMB$ 100, US$ 15) that the ETC system can absorb this cost for promotion. In the EEROM, the EEROM memory of the registered user cell phone is a kind of authentication. There is no necessary process to identify the users at the e-Center.

Me-commerce is a rising technology that most applications may be directed into possible connection with mobile phones. As for today, GSM, GPRS, 3G or even B3G technologies are still expanding. However, GSM for voice is still the most profitable system at all. There are some defeats in GSM services such as minor chance of congestion, some unavailable area, and significant longer delay at SMS (short message service). Taking the known defeats into account, the mobile ETC is still most convenient system to develop. Another problem will be the connection wire from CU, RS-232, USB, or mini USB, to the cell phones. Different specifications may vary to cause a little difficulty. Standard port of mini USB in the cell phones may be required in the future. In our tests, the proposed mobile ETC system has acceptable time delays with feasible database design. The overall test efficiency is excellent. The system stability is good that the RF frequency matches easily. The reliability of mobile base station transceiver (BTS) is good enough to offer ETC service.

The same concept may be applied directly into unmanned park lot system. This is a most sensitive problem for the next 5 to 10 years in China, due to her vast increase of personal vehicles. The low investment with high reliability and stability performance may lead its valuable application in China.

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