Electronic Toll Collection System based on Global Positioning System Technology

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***Abstract*— Currently, most of Toll Collection systems(DSRC) having many problems like infrastructures and pollution , it will be avoided by using Global Positioning System technology in Toll payment systems, Present day's toll collection systems around the world wide is DSRC (dedicated short range communication). DSRC is the infrastructure based system among toll booths. As a result of the analysis, it has turned out that only system using satellite positioning technology and mobile communications (GSM/GPS) is the best toll solution of unique capabilities. Controller all ways monitoring the GPS location values, if it matches with the already existed toll gate location values in the controller, controller send the message to the management center and a predetermined amount is automatically deducted from vehicle owner's account. This gives the many advantages system works without toll booths infrastructure, extra lanes, speed restrictions or complex structures along toll roads. The second one is much greater flexibility in defining or changing payment by simply redefining the "virtual" toll areas, eliminate traffic jams, fuel consumption and also infrastructure of toll booths.**

Keywords*— *Electronic Toll Collection; Global Position System; system frame;system application

Introduction

As one of the major research topics in intelligent transportation system(ITS) electronic toll collection (ETC) system is considered as an effective method in order to alleviate traffic congestion and jams, enhance the convenience and safety of travelers, and minimize air pollution and fuel consumption for environmental protection need. The evolution of communication technology has brought ETC systems from SLFF (Single Lane Free Flow) to MLFF (Multi-Lane Free Flow), and area wide integrated MLFF road charging system is now currently on its development. DSRC-based ETC systems will gradually evolve to the area wide integrated road charging solution based on mobile communication technology. Most of the current ETC implementations are based on the vehicle positioning system using global positioning system (GPS) and mobile communication technique [2].The current status of GPS-based ETC system worldwide is described as follows:

• **Germany**: The GPS-based ETC system has been running on-line for commercial truck toll-fee collection since 2005. This system is the only officially operating GPS-based electronic payment system in the world currently.

• **Hong Kong**: Hong Kong has finished VPS-based ETC field trial project for road charging from1997 to 2001.• **Taiwan**: The studied and tested of ETC system has been finished in 2002, and the system will be running at 2010.

• **Switzerland**: In January 2001 against the Swiss customs territory of the IGAD-led about more than 3.5t trucks pass tax levy to build a Swiss truck toll system, which is the use of GPS to determine the location of vehicles in Switzerland.

• **Singapore**: The land transport authority of Singapore issued the plan for the ERP system phase 3.GPS will be considered the primary positioning tool in the next generation ERP system and determines a vehicle's location.

The GPS SPS Signal Specification defines the service to be provided by GPS to the civil community. This document is written to satisfy the following four objectives:

1) Specify GPS SPS ranging signal characteristics.
2) Specify SPS performance, given a receiver designed in accordance with this Signal Specification.
3) Standardize SPS performance parameter definitions and measurement methodologies.
4) Define SPS performance characteristics.

The GPS Control Segment (CS) is comprised of three major components: a Master Control Station (MCS), ground antennas, and monitor stations. An overview of

the CS is provided in Figure 1 The MCS is located at Falcon Air Force Base, Colorado, and is the central control node for the GPS satellite constellation. Operations are maintained 24 hours a day, seven days a week throughout each year. The MCS is responsible for all aspects of constellation command and control, to include:

- Routine satellite bus and payload status monitoring.
- Satellite maintenance and anomaly resolution.
- Monitoring and management of SPS performance in support of all performance standards.
- Navigation data upload operations as required to sustain performance in accordance with accuracy performance standards.
- Prompt detection and response to service failures.

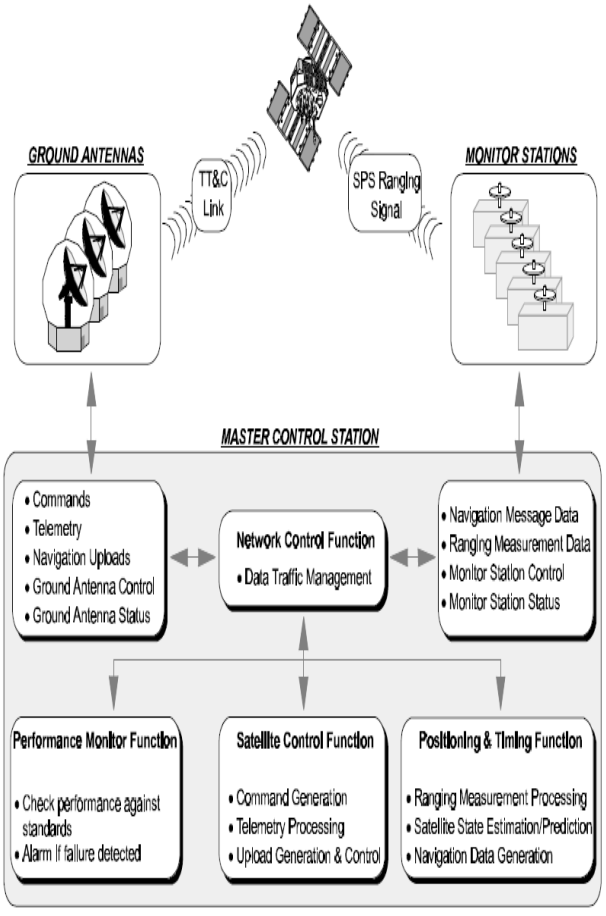

Figure 1. The GPS Control Segment

Objectives of Tolling

There are three main reasons why tolling, or road pricing, is implemented (Wikipedia: Road Pricing, 2006): Finance/Revenue Generation: To recoup the costs of building, operating and maintaining the facility. Road pricing is becoming a more appealing means of funding transportation, since revenues from federal and state gas taxes have not kept up with growth in demand for infrastructure. Moreover, toll financing allows projects to be built sooner instead of waiting for tax revenues to accumulate. Demand Management: To moderate the growth in demand on the transportation system, and to encourage more use of public transportation and carpooling. For example, vehicles are charged to enter inner London, England, as a way of regulating the demand in the region. Congestion Management: To place a price on limited roadway space in proportion to demand. In this application the toll increases with the level of congestion. In the absence of such pricing, drivers do not appreciate the costs they impose on others as a result of the congestion they cause.

Evolution of Tolling

Roadway tolling is expected to become more pervasive over time. Four stages are envisioned as beginning with corridor tolling and cordon tolling, then area-wide or vehicle-miles-traveled (VMT) tolling, and ultimately an integrated system management strategy (Deloitte Research Public Sector Study, 2003). Each stage improves system efficiency over the previous one, but also has higher complexity. Each stage also requires certain conditions before implementation. Only the first two strategies, corridor tolling and cordon tolling, have been widely implemented, with ETC being a necessity to move to the next two stages. The third stage is now being pilot tested in a few areas (discussed later), while the final stage, an integrated system, lies in the future.

SYSTEM ARCHITECTUR

The system architecture of GPS-based ETC system is illustrated in Fig. 1, which includes five key components: OBU, Enforcement System, Management Center, Clearing Center and the Payment Service Center. The working process of GPS-based ETC system is described as follows procedures:

1) Drivers goes to the payment service center registers and installs OBU and applies for pre-paid card or post-paid card.

2) When vehicle moves into the charging zone, OBU compares current vehicle position coordinate from GPS with the virtual toll node coordinate kept in the storage of OBU. After logistic determining, the OBU sets up wireless communication channel through GSM module.

3) OBU sends transaction message to management center system by the GSM module through mobile network.
4) After auditing the management center saves toll data and sends back transaction information to the OBU.
5) The OBU receives and displays the transaction result. If error transaction result is replied the OBU is abnormal payment state, the OBU is still working.
6) When the vehicle moves out the charging zone, if the OBU has abnormal state or the vehicle doesn't install an OBU the violation will be processed.
7) The clearing center clears all toll data from management center, and divides in road service providers.
8) The Payment Service Center collects toll records and clearing data for account query.

A. OBU

The working principle of the OBU is described as follows: The highway network is divided into a number of independent sections by entrances, exits and alternative interchange. Some points in sections are defined as virtual toll nodes and its coordinate are stored in the OBU memory. When vehicle moves into the charging zone the

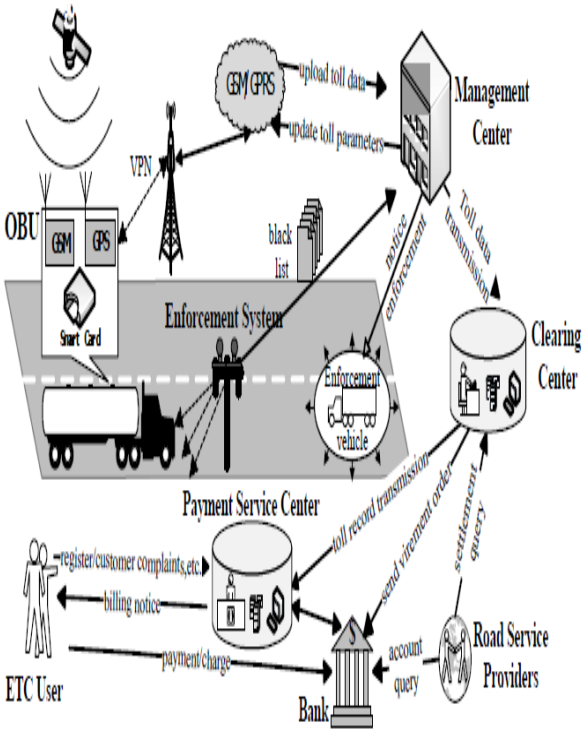

Figure 2. Architecture of GPS-based ETC system

vehicle's coordinate from Integrated GPS and Dead Reckoning (DR) positioning module are compared with the virtual toll node coordinate. If it is matching then marks this node as "1#", else gives up. Repeat comparing until it is matched again and mark the node as "2#". Through the two nodes we mark this section as "SECTION A". As shown in Fig. 2. According to the distance and the fee rate of "SECTION A" the OBU computes the payable toll. By GSM module the OBU sends toll data to the Management Center, receives transaction information and display in the screen of OBU.

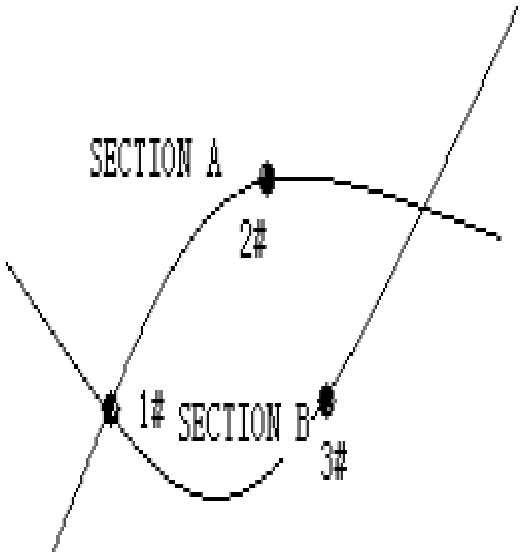

Figure 3. Charge node match

B. The Enforcement System

The enforcement system provides a mechanism to deal with the violation. The design objective is that it should catch the license plate pictures of vehicles and recognize the license number in nearly real time. Enforcement system includes fixed enforcement and moving enforcement.

a) The Fixed Enforcement: There are monitoring stations built in the expressway. When monitoring station detects the vehicle entering the enforcement line the camera catches the vehicle license plate correctly and automatic recognizes the license plate number by OCR (Optical Character Recognition) in real time. When the vehicle gets closer to monitoring station the DSRC module read the vehicle OBU status and registered information. If the license number recognized is matched to the registered and the status of the OBU is normal then deletes the images, else sends the images to the management center database for violation processing. If monitoring station doesn't detect the vehicle OBU then sends the images to the tollgate for manual toll collection.

b) The Moving Enforcement: Inspectors use the DSRC in the monitoring vehicle to read the OBU status and registered information of passing vehicle. By querying the registered user database in the in-vehicle computer if the vehicle actual information isn't match to the registered information then order the vehicle to park for violation processing.

C. Management Center

The management center is the core part of the system and functioned to tracking, monitoring, charging and guiding all the vehicles traveling on the road. Charging and guiding scheme is on the basis of collected traffic information and map database. The management center functions includes as follows:

• Manage and change the geographical scope of charging zone such as adds or deletes a toll road.
• Set up toll road fee rate and digital map data, etc.
• Collect and save toll data for clearing.
• Have extended function such as vehicle navigation, fleet management, emergency assistance, road information service, traffic flow analysis, etc.

D. Clearing Center

There are several design principles to be considered:

• Unified toll data collection.
• Unified clearing account management.
• Unified settlement time.
• Unified clearing money virement.

The clearing center clears toll data, calculates the money and sends virement command to bank. According to the command received, bank transfers money from the clearing center account to each road service provider's account.

E. Payment Service Center

The payment service center takes charge ETC users registration, smartcard issuing and customer service etc. The functions are summarized as follows:

• Manage issue and delete the encryption of ETC.
• Issuing smartcard and installing OBU.
• User registration, account recharge, consumption information query, bill printing service and arrearage notification.
• Transmit command data between payment service center and bank and collect toll data from clearing center.
• Hot line consultation and complains management, short message service.

CHARACTERISTICS OF GPS-BASED ETC

As an electronic automatic toll collection DSRC is the main technology and accepted undoubtedly. GPS is an evolutional technology for ETC as compared to DSRC and it has advantages that DSRC doesn't have. However, there are still some problems of GPS solution.

A. Advantages

• The total capital input of road side unit will be largely reduced. DSRC-based electronic toll collection system must set up gantry for each entrance in the highway network or install road side equipment in order to ensure the realization of electronic toll collection. GPS-base ETC system build some fixed monitoring stations if only, that it has monitoring function. In Germany, there are a total of 2,200 import and export about. However, it's just installed 300 fixed monitoring stations for surveillance for GPS-based electronic toll collection.
• It's easy to setup a new toll area or remove the old ones. DSRC-based ETC system can only adopt a simple uniform of district charge, if charge region need to change, it's difficult to change the infrastructure. By altering the toll mode, toll rate and virtual toll node the GPS-base ETC system can change toll area, carry out stretch and mutative toll mode. For example, the original pricing mode and the charging zone of ETC system in Singapore has been revised several times. If you use GPSbased ETC system, such modifications can be very easy to do without spending time and money to reconstruct, demolish the infrastructure facilities.
• Solving the problem of multi-path charge identification completely. By calculating the traveling distance the vehicle traveling multi-path identification problem will be completely resolved. In the DSRC-based ETC, that will be a problem.
• The interconnection problem of different DSRC provider can be broken by GPS solution because GPS adopts the worldwide standard.
• It has good expansibility and distinct advantage in integration with other ITS systems. The OBU of the GPS-based ETC system not only can serve as a tool of paying toll charge, but also can produce a variety of uses (such as vehicle navigation, traffic monitoring, emergency rescue, traffic information services, vehicle transportation management, mobile commerce, vehicle preservation, etc.) by loading the relevant application software. Correspondingly, DSRC-based toll system does not have these extensions.

B. Disadvantages

• GPS is a new coming technology; it is currently on the development and field trial stage worldwide. The business operation instance is only in Germany.
• It is more difficult in the matching process between the debit and enforcement information, so the system

needs more post-processing jobs in order to reduce the mismatch failure.

• The cost of OBU is still high for the users. With the Vehicle Positioning System technology has become more sophisticated, the OBU costs will rapidly decline, and the OBU cost gap between the DSRC-based ETC and the GPS-based ETC will be significantly reduced. Although, the OBU costs of GPS-based may be higher than the DSRC-based, but look at the total cost of the first decade of the entire system and the national policy support of initial installation fee subsidies to the GPS-based ETC users, the gap between the two systems less than 2%. DSRC and GPS technology has its own characteristics. For a relatively independent of toll road such as bridge or tunnel, DSRC-based ETC system is probably the best choice. DSRC used in a lesser extent and a single, centralized urban areas (such as Singapore) road charging is also very appropriate. However for a larger toll road network, GPS-based ETC system is more suitable. Germany for instance, the truck toll system will calculate and the toll in accordance with its mileage and weight. Currently New Zealand is also developing a similar approach, because the charges scope were larger and charges node widely distributed, using DSRC technology is more difficult and costs are also high, GPS technology may be a better choice.

APPLICATIONS

DSRC-based ETC projects, but the biggest problem is the lack of size. The reason is that Chinese highway toll station entrances and exits are built, so it must transform the existing driveway to electronic toll lanes, resulting in investment cost more. But the GPS-based ETC system has many advantages; vehicle location can be used across the country and its wide range of potential applications making it the best choice of Chinese highway network charges. Networking electronic payment (NEP) is the inevitable requirement for actualize Chinese highway network electronic toll. NEP records the information of vehicles and the entrance into the smart-card when vehicle through entrance of the site, reads card information while through exit, calculates and deducts from the amount of the card. Therefore, for actualizing the GPS –based ETC based on networked electronic payment, it can be divided into the following four-step implementation:

1) The first step. Achieving the provincial highway networking electronic payment. Most provinces have achieved highway networking charge that laid the foundation for networking electronic payment. While achieves the provincial-level networking electronic payment, establishing provincial management control center and clearing center. This can serve as the provincial-level management control center and clearing center of the GPS-based ETC system.

2) The second step. Achieving the provincial-level GPS-based ETC system and the regional-level (such as the Yangtze River Delta region) networking electronic payment. While achieving provincial-level GPS-based ETC system, according to entrance exit and cloverleaf junction of provincial networking highway, establishes virtual charge points. For conditional toll station (such as the main-road toll stations) can rebuild special ETC lanes, build DSRC antenna, vehicle image capture system, electric balustrade, so as to prevent non-ETC vehicles break through the barrier and fleeing charges. For unconditional toll station (such as branch-road toll stations) can install DSRC antenna at the toll lane. The system reads the payment status of the OBU and verifies vehicle information. Vehicle that doesn't install OBU still take the manual toll lanes. While achieving regional-level networking electronic payment, establishing regionallevel clearing center, through the clearing center, the toll of the inter-provincial networking electronic payment will be split to the each provincial clearing center.

3) The third step. Achieving the regional-level GPS networking ETC system and popularizing inter-regional networking electronic payment gradually. Regional-level GPS-based ETC system is implemented based on the regional-level networking electronic payment. In the nationwide implementation of the inter-regional electronic payments, it should implement electronic payments based on the interconnection two regions, establish interregional l clearing center. Then extends to the surrounding adjacent areas and expansion of inter-regional clearing center to increase the settlement area.

4) The last step. Achieves national networking electronic payment. Inter-regional clearing center will split the toll to the regional-level clearing center, and then split the toll from the regional-level to the provincial-level clearing center, finally split the toll to each highway companies.

CONCLUSION

With the development and improvement of GPS-based ETC system, along with its flexible definiens of charging zone and charging mode, better compatibility with other system in ITS and other advantages that DSRC-based ETC system lacking. We believe that in

the near future, GPSbased of ETC will be widely used in internal road charging. In this paper we described the frame composing and working flow of the system, discussed the design of GPS-based ETC system components detailed. The application of GPS-based ETC in internal expressway network toll collection will be the major issues of our future work.

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