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Design and implementation of electronic toll collection system based on vehicle positioning system techniques

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ABSTRACT

Currently, most electronic toll collection (ETC) systems around the world are implemented by DSRC (dedicated short range communication) technology. However, area wide integrated MLFF (multilane free flow) road charging system is now currently on its development to replace DSRC-based ETC systems. VPS (vehicle positioning system) based ETC system is a category of location based service which tolls vehilces by determining if they move into the charging zone. It is an evolutional technology for area wide integrated road charging solution, which achieves the goal of electronic payment or electronic toll collection by a totally different scheme comparing to traditional DSRC-based technology. In this paper, the design and implementation of VPS-based ETC system is detailedly discussed, and a debit transaction VPS system field test had been practiced in the freeway of Taiwan.

1. Introduction

Electronic toll collection (ETC), also known as electronic payment and pricing system, is one of the major research topics in intelligent transportation system (ITS) [1]. ETC is an implementation of a road pricing concept in order to create benefits such as increasing the capacity of toll stations, reducing toll paying time, enhancing the convenience and safety of travelers, and minimizing air pollution and fuel consumption. It enables freeway toll plaza, bridge, tunnel, and turnpike operators to save on staffing costs while reducing delay for travelers and improve overall traffic performance. ETC system determines whether the vehicles passing are enrolled in the program, alerts enforcers for those that are not, and debits electronically the accounts or the amount in the IC card of registered cars without their stopping. The traditional technologies used in ETC system are classified as DSRC (dedicated short range communication) system since the on board unit (OBU) installed in the vehicle can only communicate with the road side unit (RSU) within a short range area, for example, 30 m. The technologies used in DSRC-based ETC system are classified by two categories: infrared and microwave, which are named by their communication media. The evolution of ETC technology has brought DSRC-based ETC system from SLFF (single lane free flow) to MLFF (multilane free flow), which do not constrain the vehicle moving on single lane while moving through the tolling zone. However, there are several drawbacks in DSRC-based ETC system: complexity, cost ineffective, difficulty in system integration, and lack of RSU re-location flexibility.

Area wide integrated MLFF road charging system is now currently on its development to replace DSRC-based ETC systems. Vehicle positioning system (VPS) technology has become the new trend for road charging system, which implements ETC system based on positioning and mobile communication technologies. There are two major differences between VPS-based and DSRC-based ETC systems: communication mechanism and toll collection media. The communication mechanism used in VPS is mobile communication such as GPRS/UMTS/HSPA, which are the standard mobile communication protocols. Although there are some standards or protocols for DSRC-based ETC, most of them cannot cooperate with each other. Comparing to DSRC-based ETC system, VPS-based ETC system has following advantages: cost effective, RSU simplification, no communication zone restriction, service extensibility, and easy to migrate from lane-based to distance-based toll collection scheme. The toll mechanism in VPS is based on interaction between OBU and backend system through mobile network instead of the communication with RSU in the DSRC-based ETC system. The advantage of this mechanism is that there is no need to build up complex RSU as in DSRC-based ETC system, which has the flexibility of tolling zone relocation. The cost of system construction and maintenance can be largely reduced. For the extensibility issue, since there are mobile communication, positioning and electronic payment mechanisms in VPS-based ETC system, it can be

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easily extended to telematics service or m-commerce service without extra facilities in in-vehicle device (OBU), for example, park fee collection, vehicle navigation, etc. Furthermore, OBU in DSRC-based system is usually proprietarily owned by operator or manufacturer, but it is users' choices in VPS-based ETC system, such as dedicated OBU, VPS enabled smartphone/PDA/PND (personal navigation device)/UMPC (ultra mobile PC), etc.

ETC system is operated by the coordination of several subsystems, including debit transaction subsystem, enforcement system, OBU, mobile communication system and the backend system. Enforcement subsystem consists of AVI (automatic vehicle identification) and license number recognition. In this paper, we discuss the design issues about VPS-based ETC system, and a prototype system including backend system (debit transaction subsystem) and frontend devices (OBU) are designed and implemented for field test. The system adopts GPRS mobile network and GPS positioning system as the basis. Several types of OBU including dedicated OBU, smart phone, PDA are implemented. Field test is carried out in the National freeway No.1 and No.3 in Taiwan for several months and a testing fleet consisting of 10 freeway scheduled buses is created in cooperation with the bus company.

The following sections are arranged as follows. Section 2 introduces the background and related works of VPS-based ETC system and some systems are discussed, Section 3 discusses the system architecture and tolling process of VPS. The design and implementation of VPS components is discussed in Section 4, including OBU, messages protocol, enforcement system and backend system. In Section 5, units test and field test are discussed. Besides, a debit transaction system had been implemented, where a test fleet consisting of 10 vehicles were joined for field test in the national freeways in Taiwan. Finally, concluding remarks and future research are given in Section 6.

2. Background and related work

DSRC-based ETC technique is in its development towards to the precision of MLFF [2] and optimum configuration [3]. Currently in worldwide, many countries and cities have conducted the DSRC-based ETC system for their road pricing or congestion pricing policies, and many schemes have been adopted: Stop and Go, SLFF, and MLFF [4,5]. For example, Taiwan [6] and South Korea [7] have announced the national wide ETC service using the DSRC-based ETC system since 2006. On the other hand, ANPR (automatic number plate recognition) technique is also applied for the urban cities road pricing, which is adopted by several cities: London, Rome, Edinburgh, etc. However, the identification precision of ANPR technique which is not as good as the DSRC or VPS technique may result in extra manual operation cost. It is considered more suitable to apply to the enforcement system as a backup of toll collection system.

Vehicle positioning technique currently has been applied to many popular applications, including vehicle navigation, vehicle tracking, fleet management, location based services, and telematics services. VPS-based ETC system is a category of location based service which tolls the vehicles by determining if they move into the tolling zone, and it can be used for the freeway toll collection or the road pricing in the urban area. The concept of toll collection by VPS scheme began in [8], and the first VPS field test project ERP (electronic road pricing) was carried on in Hong Kong in 1997. The overview and design issues of the VPS-based ETC system were further discussed in [9] and [10]. Currently, there are some countries have conducted or prepared to conduct VPS based toll collection scheme for road pricing. Toll Collect Project [11,12] for the trucks on Autobahns in Germany has been in operation since 2005, which tolls the trucks by mileage based scheme calculated by the OBU, but the enforcement system is still based on the DSRC technique. HVF (heavy vehicle fee) project [13,14] in Switzerland combines DSRC and VPS technique to collect toll fee for heavy vehicle. In US, traffic choices study project had a field test for road pricing by VPS technique in Puget Sound [15]. Eight cities in Europe had joined the PRoGRESS project [16] for urban road pricing, which has the goal of "demonstrate and evaluate the effectiveness and acceptance of integrated urban transport pricing schemes to achieve transport goals and raise revenue" [16]. The comparison of technology and the toll schemes adopted by these cities are listed in Table 1. Among them, three cities adopted VPS technique including Copenhagen, Bristol, and Gothenburg for different toll schemes: cordon-based, zone-based, and distance-based.

3. VPS system architecture

The system architecture of VPS-based ETC system is illustrated in Fig. 1, which includes four key components: OBU, enforcement system, mobile communication system, and backend system. It combines several technologies including vehicle positioning, mobile communication, vehicle detecting, and classification, and auto license plate recognition, OBU and backend system. OBU is a device installed in the vehicle, with computing, positioning (GPS) and

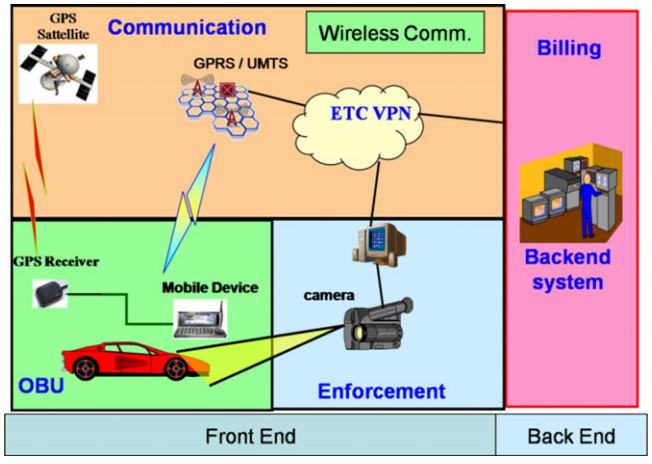

Fig. 1. Architecture of VPS-based ETC system.

Table 1
Comparisons of the toll scheme and technology adopted in PRoGRESS [16]

Scheme concept	Road-pricing technology basis		
	DSRC-electronic tag	ANPR	GPS
Cordon (per trip)	Rome, Helsinki	Bristol, Genoa, Rome	Copenhagen, Bristol
Cordon (per day)		Edinburgh	
Zone (per trip)	Trondheim, Helsinki		Copenhagen
Distance-based			Copenhagen, Gothenburg, Bristol