Development and evaluation of urban road pricing system based on active DSRC and contactless IC cards

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Abstract: In big cities in Asia, a road pricing system is one of the effective solutions for traffic congestion. We have developed “Integrated Urban Road Pricing system” based on active DSRC communication proven in Japan. Our internal battery OBU (on-board unit) has contactless IC card interface able to accept the cards which circulate widely as a payment media in Asian countries. Wiring work is not needed for installation, and introduction of OBU is easy for users. By a trial in Malaysia for one year, our system has been operated in practical use without trouble as a road pricing system.

Keywords: ITS, on-board unit (OBU), DSRC, contactless IC card

Classification: Terrestrial Wireless Communication/Broadcasting Technologies

References


1 Introduction

Traffic congestion especially becomes a critical problem of the developing countries in Asia. In big cities, a road pricing system is one of the effective solutions for traffic congestion. We have developed “Integrated Urban Road Pricing (IURP) system” based on active DSRC (Dedicated Short Range Communication) communication proven in Japan. Our battery type OBU (on-board unit) has the interface with high-security contactless IC cards able
to accept the cards which circulate widely to purchase as a payment media in each country of Asia. In addition, wiring work is not needed for installation to vehicle and introduction of OBU is easy for users, and the spread of OBU can be expected. As power consumption of OBU which uses active DSRC is large, it is usual to supply power by an external battery. We have developed the internal battery OBU whose power consumption could be cut down 30% by sleep and wake-up control and the battery life more than 2 years.

By a trial on the express way in Malaysia for one year, it is proven that our IURP system has been operated without trouble as a road pricing system and error rate is under 1/100000 by long-term stable operations.

2 Problem setting and required conditions

2.1 Active DSRC communication
Active 5.8 GHz DSRC is adopted that is used for ETC in Japan. DSRC is compliant with ARIB STD-T75 [1], STD-T88 [2], and composes a steady communication zone that is the range of 20 m in the center of the base station. One base station communicates simultaneously with multiple mobile stations. Wide communication area and high transmission speed (4 Mbps) is realized by active communication method and it can be assumed to be commonly used for both single lane barrier methods and multiple free flow lanes.

2.2 Contactless IC cards
We have target for multiple contactless IC cards with high-security, such as Mifare [3] Classic, Mifare DESfire, and Mifare Plus as a payment media of OBU. These contactless IC cards circulate to purchase a lot in each country of Asia and are also used actually in public transportation. Therefore, users need not for new card operations and can use existing infrastructure.

2.3 Battery type OBU
Battery type OBU is operated by an internal battery. When installing battery type OBU to the vehicle, wiring work is unnecessary and the end users can easily install OBU. On the other hand, OBU has the risk of fraud operations such as swapping. We develop measures concerning low power consumption and illegal use to put battery type OBU into practical use, and the power management function and the setup function are added.

2.4 Required conditions
The IURP system we propose in this paper is the system corresponding to issues of road pricing in Asian countries, where a high-speed and high-quality, and high-security means of communication is required by combining road to vehicle communication and contactless IC card access. Here, required conditions that the system should meet are as follows.

- Completing the fee collection correctly and securely at the vehicle speed of 80 km/h, and the information transmission must be high-speed and low latency.
Accepting multiple contactless IC cards with high-security, such as Mi-
fare Classic, Mifare DESfire, and Mifare Plus, installing Mifare SAM
(Secure Application Module). The battery life of OBU should be more
than 2 years.

3 Proposal of IURP system

We propose the IURP system that uses road to vehicle communication, con-
tactless IC cards, and battery type OBU as a system that satisfies the re-
quired conditions. For the proposed system, active DSRC is adopted as road
to vehicle communication, Mifare SAM is adopted as contactless IC card
access.

3.1 System configuration

IURP system is composed of Lane controller (LCL), Key server, roadside unit
(RSU), roadside antenna, OBU, and contactless IC card. LCL and roadside
antenna communicate with OBU using DSRC, and OBU accesses the IC
cards by Mifare interface. Fig. 1 shows the system configuration of IURP
system. IURP system corresponding to Mifare Classic, Mifare DESfire, and
Mifare Plus, it is necessary to carry Mifare SAM on either RSU or OBU.

![Diagram of IURP system]

Fig. 1. Configuration of IURP system.

3.2 Communication sequence of DSRC and Contactless IC
card

We develop the communication sequence that combines DSRC and contact-
less IC card. Fig. 2 shows the communication sequence for IURP system.
OBU can perform card access processing only in DSRC communication area,
and out of communication area card access is not carried out (operation by
transparent transaction). As a result, it is possible to improve security of the
system as follows.

- The card key needed for accessing contactless IC card is stored in RSU,
  not stored in OBU.
Fig. 2. Communication sequence of DSRC and contactless IC card.

- The procedure of access to the memory in contactless IC card is not controlled by OBU. LCL accesses IC cards directly through DSRC.

4 Development of in-vehicle system and roadside system

4.1 On-Board Unit (OBU)

OBU is compliant with DSRC section standard specification of ITS OBU [4], and has the functions for DSRC communication. Users can easily install the holder with double-sided to the windshield of vehicle. The main body of OBU can be attached to the holder and detached from the holder when OBU not used for anti-theft.

4.2 Power management function

The operational mode of OBU is classified into “Deep sleep”, “Sleep”, and “Active”. When a card is not inserted to OBU, the state is “Deep sleep”. If a card is inserted, OBU shifts to “Active”, performs authentication of contactless card, and shifts to “Sleep” after a definite period of time. When OBU detects the career wave from RSU on “Sleep”, OBU wakes up shifting to “Active” and performs DSRC, and after communication shifts to “Sleep”. Making CPU of OBU sleep, sleep time becomes doubled and the power consumption could be cut down 30%. When a card is extracted, OBU shifts to “Deep sleep”.

4.3 Setup function

As users can attach or detach OBU to the vehicle easily, fraud operations by swapping are likely to occur. In the memory of OBU, setup information such as OBU ID and vehicle class etc. is written by setup. Using DSRC setup information is transmitted to LCL. On the other hand, the vehicle classification unit is connected with LCL, and when vehicle class un-matching is detected, cooperating with the enforcement device, we can take measures for the violation vehicles.
4.4 Fee collection function
The basic procedure of fee collection is as follows.

(1) By start request from LCL, DSRC is started and linked with OBU (connection).

(2) OBU authentication and card authentication are performed.

(3) OBU ID, contractor number, and card ID are read, and card key is generated.

(4) The amount of fee collection is determined using OBU ID and attribute, etc. Card balance is checked and charge is deducted.

(5) Charging result is expressed by OBU and released (disconnection).

4.5 Contactless IC card access function
The data accesses in contactless IC cards through DSRC are shown in Table I. Here, data volume of each item is 16 bytes. OBU performs card access processing in DSRC communication area.

<table>
<thead>
<tr>
<th>Data access items in contactless IC card</th>
<th>Data access points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entrance</td>
</tr>
<tr>
<td>(1) Contractor info (Read)</td>
<td>○</td>
</tr>
<tr>
<td>(2) Balance (Get value)</td>
<td>○</td>
</tr>
<tr>
<td>(3) Balance (Dec)</td>
<td>○</td>
</tr>
<tr>
<td>(4) Balance (Read)</td>
<td>○</td>
</tr>
<tr>
<td>(5) Transaction history (Read)</td>
<td>○</td>
</tr>
<tr>
<td>(6) Transaction history (Write)</td>
<td>○</td>
</tr>
<tr>
<td>(7) Charging history (Read)</td>
<td>○</td>
</tr>
<tr>
<td>(8) Charging history (Write)</td>
<td>○</td>
</tr>
<tr>
<td>(9) Entrance info (Read)</td>
<td>-</td>
</tr>
<tr>
<td>(10) Entrance info (Write)</td>
<td>○</td>
</tr>
</tbody>
</table>

5 Feasibility test by experimental system

5.1 Evaluation of simulation results
As a system configuration roadside SAM carried on RSU or in-vehicle SAM carried on OBU could be considered, performance of each composition are compared by the simulation. As the simulation conditions, one frame cycle time of DSRC is 7 ms and IC card transmission speed is 106 kbps. As a result, in the case of roadside SAM, DSRC communication time including IC card accesses becomes 281 ms and communication area needs 7 m for the fee collection at the vehicle speed of 80 km/h. In the case of in-vehicle SAM, DSRC communication time is 217 ms and communication area becomes 5 m, though it is satisfied on the system operation. Therefore, the roadside SAM composition which cuts down OBU cost has adopted. A battery life of OBU corresponding to multiple cards with low power consumption design is calculated. As the OBU use model in one day, “Deep sleep” is 16 h, “Sleep” is 8 h
(sleep time becomes doubled), and “Wake-up” is 8 times. Adopting lithium primary battery of nominal 2400 mAh, the battery life of OBU becomes 2.2-2.3 years.

5.2 Evaluation of trial in Malaysia
We have executed a trial of the single lane at the tollgate of the express way in Malaysia for one year operations. The experimental OBUs have been distributed to the selected users, and the contactless IC cards issued for public transportation are used as a payment media. As a result, our IURP system has been able to prove interoperability with the public transportation cards. The users have been able to use existing card infrastructure and enjoy convenience. It is proven that our system has been operated without trouble as a road pricing system and error rate is under 1/100000 by long-term stable operations.

6 Conclusion
By the simulation results, the fee collection corresponding to all target cards can be completed in the communication area at the vehicle speed of 80 km/h. Moreover, it is satisfied that the battery life of OBU is more than 2 years.

In the trial of the single lane in Malaysia for one year, our IURP system which adopts active DSRC, contactless IC cards, and battery type OBU has been operated in practical use without trouble and the effectiveness of the system has been evaluated. As a result, we get the prospect that the roadside system is possible to upgrade single lane barrier methods to multiple free flow lanes and the IURP system is able to share use. In the future, we will aim to upgrade the IURP system to the best traffic demand management system.