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Electronic Toll Collection System Using Radio Frequency Technology

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Abstract ***-This paper focuses on an electronic toll collection (ETC) system using radio frequency (RF) technology. Research on ETC has been around since 1992, during which RFID tags began to be widely used in vehicles to automate toll processes [1]. Next method proposes a very simple method for enhancing the performance of infrared electronic-toll-collection systems, resulting in longer communication time interval for the data transmission between the on board unit (OBU) and the road side unit (RSU). The proposed RF system uses antenna that are mounted on the windshields of vehicles, through which information embedded on the tags are read by RF readers, the toll debit will be taken from the owner's bank account. The proposed system eliminates the need for motorists and toll authorities to manually perform ticket payments and toll fee collections, respectively. Data information are also easily exchanged between the motorists and toll authorities, thereby enabling a more efficient toll collection by reducing traffic and eliminating possible human errors.***

Keywords-Electronic Toll Collection (ETC) , On board Unit (OBU) , Road side System (RBU) , Radio Frequency (RF) .

I. INTRODUCTION

There are two major types of electronic-toll-collection (ETC) systems currently used in the world, namely single lane and multilane free flow. It is well known that multilane free-flow systems represent much greater complexity than single-lane systems, but the former is more convenient for faster traffic throughput, especially in high-traffic-loading areas due to less restriction on vehicle passing speed. For communication between roadside units (RSU) and on board units (OBU) in ETC systems, there are several different media being utilized, such as 900-MHz, 2.4-GHz, and 5.8-GHz microwave based on dedicated short-range communication (DSRC), as well as 870-nm infrared. For ETC applications, a sufficient communication time interval is necessary to allow for the complete transfer of all the information between a roadside unit (RSU) and an on-board unit (OBU) while the vehicles are rapidly traveling through the communication region. However, for windshields with high infrared attenuation, the problem of severe shrinkage of the communication region is very serious [1], in particular, for vehicles at high speed.

Measurements for various kinds of commercial windshields have confirmed that the transmitter for 870-nm infrared light varies from 0.8 to 0.15, i.e., with 20% to 85% attenuation. Hence, attenuation has a significant effect on infrared ETC systems.

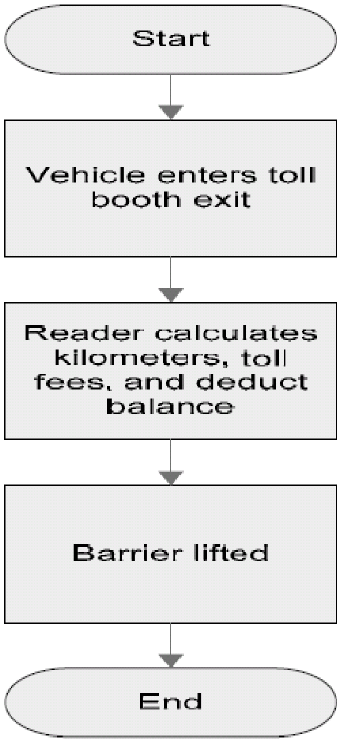

Figure. 1. Flow chart of system design

In figure 1, the flowchart of the entire system is given. In an automatic debiting system on the road network, it is essential that the exchange of information between roadside system (RSS) and the on-board unit (OBU) in a moving vehicle is reliable and fast. The most obvious advantage of this proposed technology is the opportunity to eliminate congestion in tollbooths, especially during festive seasons when traffic tends to be heavier than normal. It is also a method by which to curb complaints from motorists regarding the inconveniences involved in manually making payments at the toll booths. Other than this obvious advantage, applying ETC could also benefit the toll operations such as faster and more efficient service by avoiding exchanging toll fees by hand .Other general advantages for the motorists include fuel savings and reduced mobile emissions by reducing or eliminating deceleration, waiting time, and acceleration.

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Also this system assures quick checking of vehicle details using simple RF and provides a comfortable journey for the public.

This is the task of the dedicated short-range communication (DSRC) system, one of the subsystems of the ADS. Other subsystems are used for vehicle detection, coordination and license plate registration.

II. MODELING

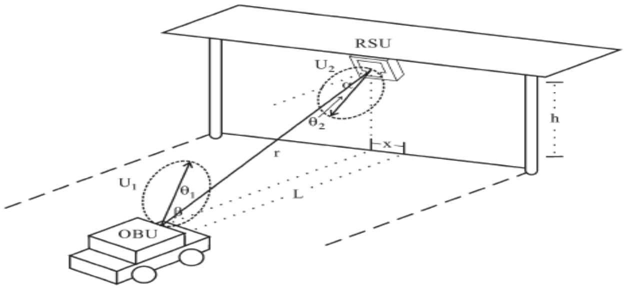

Figure.2. Block Diagram of Monitoring the vehicle

In figure 2, vehicle monitoring is shown . In order to simulate a complete ADS[2], we have to model the different subsystems [3]. In this paper, we are only interested in the communication subsystem: the link between the microwave antennas at a gantry above the road (RSS) and the small patch antenna (OBU) in moving vehicles. Via this link, a certain fee that has to be paid for the passage is collected. When the vehicles are not equipped with an OBU, their license plate will be registered, which is a task of the other subsystems of the ADS (detection and registration). The other subsystems are out of the scope of this paper. A communication link for electronic payments has to be reliable. To prove the reliability of such a system, a detailed analysis of the occasional errors is needed. Large-scale simulations are well suited for this job. The aim of this paper is to find the right level of detail needed for such analysis.

III. SIGNAL STRENGTH RELATION

In ETC systems, the radiation power of the RSU is generally stronger than that of the OBU, so that the downlink communication region is much greater than that of the uplink. Hence, the capability of the uplink communication is crucial for data transmission. Therefore, we initially focus only on the uplink transmission.

A.Uplink Signal-Strength Relation

In a previous work, the uplink signal path under the single lane condition was analysed [1]. The signal strength received by the RSU from the OBU emission can be described by

$$S = A_0 \frac{U_1(\theta_1, \phi_1) U_2(\theta_2, \phi_2)}{r^2} \qquad (1)$$

Where $A0$ is the amplitude constant, $U1(\theta 1, \varphi 1)$ is the radiation pattern of the OBU, $U2(\theta 2, \varphi 2)$ is the receiving pattern of the RSU, and r is the distance between the OBU and the RSU. $U1$ and $U2$ are functions of the emitting direction $(\theta 1, \varphi 1)$ and the receiving direction $(\theta 2, \varphi 2)$, respectively, where $\theta 1$, $\varphi 1$,$\theta 2$, and $\varphi 2$ are defined, following the conventional spherical polar coordinates (note that $\varphi 1$ and $\varphi 2$ are not displayed in this 2-D figure). For instance, for a typical infrared short-range communication system for the ETC applications previously discussed [1], where the half-intensity angle of the emitting module of OBU is $\Phi 1/2 = 24^\circ$,1 the radiation pattern is calculated by $\cos 7.5\ \theta 1$, and the receiving pattern of RSU is a conventional cosine function calculated by $\cos\ \theta 2$, the relative signal strength received by the RSU and emitted from the OBU can be described by

$$S_u = 1000 \frac{\cos^{7.5}\theta_1 \cos\theta_2}{r^2} \qquad (2)$$

where we adopt an arbitrary scale (with $A0$ arbitrarily set to1000) [1]. For this arbitrary amplitude constant $A0 = 1000$, the signal-strength threshold of this system can be determined by measurement [1] and was shown to be $Sth = 9$. With the aid of this signal-strength relation and the threshold, the performance of the system can successfully be analyzed [1]. The utilization of the $\cos n$ function, i.e., $\cos n\ \theta$, to calculate the radiation and receiving patterns is very effective

IV. THE ARCHITECTURE

The fact that in both multilane-free-flow and single-lane ETC systems there are huge volumes of data in several simultaneous message traffic between RSUs and OBUs in all traffic lanes is without further discussion. In multilane-free-flow systems, the vehicle passing through the data-communication region in the ETC plaza may change travel lanes during data transmission between its OBU and the RSU on the previous travel lane. Because of this, the data transmission between the OBU and the RSU on the previous travel lane may very often be incomplete and must be performed consecutively by the RSU mounted on the current travel lane, into which the vehicle has entered [see Fig. 1(b)]. This is the main difference between multilane-free-flow and single-lane systems. Hence, the trajectories of moving vehicles passing through the data-communication region in the ETC plaza before, during, and after each data communication event are very important information for correctly performing ETC transactions in multilane free-flow systems. This is to say that besides the simultaneous data communication between RSUs and OBUs in all traffic lanes, we also need to track all vehicles passing through the toll-collection plaza like an active seeker in an advanced missile. The purpose of vehicle-trajectory tracking is to decide the timing for separating the whole data transmission into several segments so as to be able to communicate in contiguous traffic lanes consecutively, while the vehicles change traffic lanes. The technology of multi target tracking has been well developed in radar systems. An abundance of data-transmission techniques is also available. Now, we discuss the essence of this architecture, which combines frequency multiplexing and two techniques widely used in radar systems, including pulse ranging and fine target-direction determination.

A. Frequency Multiplexing and Wave Emission

The architecture for simultaneously performing multi target tracking and multi data communication between vehicles and the ETC system is based on the idea of using different carrier frequencies for different purposes. Fig. 2 shows an example of frequency multiplexing [9] for an appropriate frequency band arrangement among different traffic lanes. This figure illustrates that we use separate emitting antennas for each traffic lane, but only one common receiving antenna for collecting all return signals.

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The frequency bands utilized in different traffic lanes are distinguishable. There is a frequency discrepancy Δf between contiguous lanes. Furthermore, the carrier frequencies for target tracking and data transmission in each traffic lane are also different. The difference between them is δf.

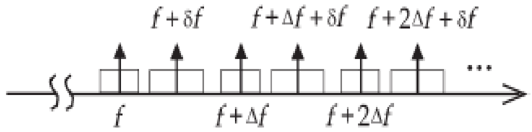

Figure 3.Arrangement of frequency bands for simultaneously performing multitarget tracking and multidata communication in millimeter waves ETC systems.

Fig. 3 shows. The arrangement of frequency bands for this architecture. Fig. 4 shows a simple block diagram of the transmitter of our architecture. A local oscillator creates a continuous wave of frequency f. This frequency is allotted to lane 1 for data transmission, i.e., the baseband data-communication signal is mixed with it directly.

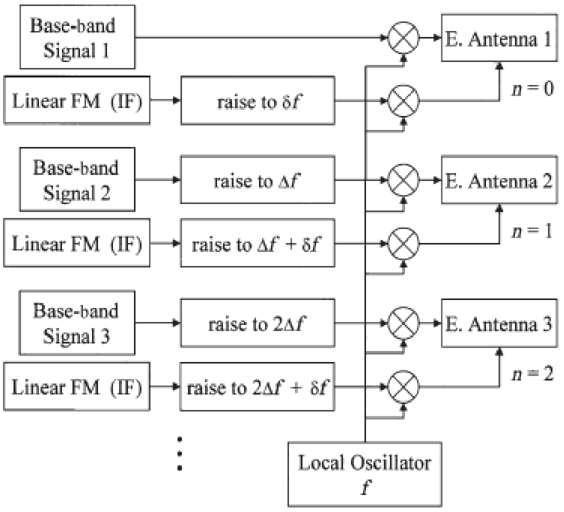

Fig. 4. Block diagram of the transmitter.

The carrier frequency for target tracking in this lane is assigned $f + \delta f$. For target tracking, we need a linear frequency modulation (linear FM) in the intermediate frequency (IF) band, in order to perform pulse compression in the receiver, as will be discussed later in Section II-C. We do this at frequency δf and then raise it to $f + \delta f$ by mixing it with the local oscillator. Finally, these two signals at f and $f + \delta f$ are combined and sent to the emitting antenna.

The frequency bands utilized in other traffic lanes are raised by Δf in turn. Hence, the baseband data-communication signal and the IF band tracking signal in each lane should first be raised to $n\Delta f$ and $n\Delta f + \delta f$, respectively, where $n = 0, 1, 2, 3, \ldots$ for lane 1, lane 2, lane 3, lane 4, . . ., in turn. These are shown in the blocks "raise to $n\Delta f$" and "raise to $n\Delta f + \delta f$" in Fig. 4. For doing all of these, we need two other local oscillators with frequencies δf and Δf, a frequency multiplier, as well as some other mixers, which are implicitly included in each block, and not shown explicitly. All these signals at frequencies $n\Delta f$ and $n\Delta f + \delta f$ are then mixed with the local oscillator f. Finally, in each traffic lane, the signals in the target-tracking channel and the data-transmission channel are Combined and sent to the emitting antenna. The result is that the carrier frequencies for downlink data transmission are $f + n\Delta f$ (1) Fig. 5. Block diagram for choosing an uplink carrier frequency in an active OBU. Where $n = 0, 1, 2, 3, \ldots$ for lane 1, lane 2, lane 3, lane 4, . . ., in turn, and the carrier frequencies for target tracking are $f + n\Delta f + \delta f$ (2) also $n = 0, 1, 2, 3, \ldots$, in turn, for each traffic lane. Here, the purpose of the target-tracking channel is to construct high-resolution mono pulse radar [10], [11]—we can obtain the target distance from pulse ranging and target direction from amplitude comparison, as will be discussed later.

B. Active and Passive OBU Systems

The OBU of the current microwave ETC systems can be divided into two categories, active and passive. During the uplink data transmission in passive systems, the emitting antenna of each road top unit1 emits a continuous wave. The OBU mounted in the vehicle receives this wave, digitally modulates it, and then sends it back; whereas in active systems, the OBU can actively emit uplink signals. In our architecture, we use different frequency bands in different traffic lanes (see Fig. 2). Therefore, in passive systems, the carrier frequencies of the reflected uplink signal from different traffic lanes are automatically distinguished. For active systems, the OBU can be endowed with the ability of choosing one of several preselected frequencies as the carrier frequency for uplink data transmission, according to previously received downlink carrier frequency. This can be realized, for example, as shown in Fig. 5. The received downlink signal from the receiving antenna after down conversion can be sent to a filter bank or a fast-Fourier-transform (FFT) analyser to determine the received downlink carrier frequency. Then, according to this frequency, we can choose a corresponding uplink carrier frequency, this is the task of the "Decision Making" block in Fig. 5. Clearly, this function will greatly increase the circuitry complexity compared with that of passive systems. Nevertheless, for both cases in our architecture, the uplink signals from vehicles in different traffic lanes can be distinguished without difficulty by their carrier frequencies.

V.RESULT ANALYSIS

Table 1.Communication Results for the different Hierarchial level without contribution of any other level .

	No transaction
Transmitter Geometry model	41.68%
Transmitter Field model	34.53%
Single-Receiver model	0.00%
Single Vehicle model	0.03%
Multiple Vehicle model	0.16%

Complete transaction	Running time
58.32%	0h03
65.46%	0h08
97.54%	3h21
91.24%	4h45
90.13%	5h33

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In this section, we will distinguish three different outcomes of the transaction: no transaction, an incomplete transaction, and a complete transaction. For each hierarchical model, we will predict the number of cases and record the computational price paid for the increasing level of detail. In Table I, one can see that the detailed *multiple-vehicle model* needs more than 100 times the running time of the transmitter-geometry model. All calculations where performed on Sparc Ultra 10 workstations with a 300-MHz processor. The simulation results are based on 10 000 passages of vehicles, all equipped with an OBU.The *single-receiver model* has better results compared to both transmitter models for two reasons. The first reason is related the RSS antenna pattern under the gantry. The *transmitter-field model* contains only the main lobe. Yet, for many transactions, a message has to be exchanged when the OBU is between the main lobe and the first side lobe. For the *single-receiver model*, the message is exchanged in the side lobe, after a number of retries.

	No transaction	Complete transaction	Running time
Single-Receiver model	0.01%	98.01%	0h33
Single Vehicle model	0.01%	91.72%	0h45
Multiple Vehicle model	0.01%	91.22%	1h04

Table 2. Communication resuts for the different hierarchical level with filtering by the transmitter field model

In the *transmitter-field model* there is no side lobe, so the transaction is not completed. Detailed analysis showed that the sidelobe is involved in 13% of the transactions. The second reason is that the *transmitter-field model* rejects all communication when the bit error rate is worse than 10 . In practice, messages can still be exchanged for rates 10 , although retries become likely. This effect contributes to successful transactions for 36% of the passages.

The percentage of completed transactions predicted by both *vehicle models* is lower than that of the *single receive model*.In this model, the receiver is a free-floating device in the air, windscreen and reflections are not taken into account. The influence of the reflections on the received signal can be both positive and negative. For instance, the variations in the signal level obtained using the *single-vehicle model* are between 3.3 and 12.8 dB, and between 41.4 and 35.8 dB for the *multiple-vehicle model*, compared to the *single-receiver model*.On the average, the reflection increased the power level in the receiver.The fact that the *transmitter-field model* is more stringent makes it possible to use this model as a filter for a more detailed model. This filtering works as follows. When the *transmitter-field model* predicts a successful transaction, this result is used. When the *transmitter-field model* predicts an incomplete or unsuccessful transaction, a patch antenna model like the *multiple-vehicle model* is used for a precise simulation of the transaction. With this filtering, not more than 20% of the running time is needed, without a significant loss of accuracy(Table II).Although the hierarchical approach, proposed in this paper,requires more effort for the modeler, the advantage is that simulations are performed in less time. Furthermore, insight is gained into which assumptions have the greatest influence on the per performance of the communication link.

VI. CONCLUSION AND FUTURE WORK

The architecture presented in this paper describes a multi-free-flow of traffic using electronic-toll-collection (ETC) systems. The principle idea is that from the information of the trajectories of the vehicles passing through the ETC plaza, it has been made easy to decide the timing for separating the whole data transmission into segments so as to communicate in contiguous traffic lanes consecutively, while the vehicles change lanes. Another advantage of this architecture is that the millimetre wave range can provide a very wide communication bandwidth to overcome the shortcoming of bandwidth deficiency present in the centimetre-wave range. Also the information regarding the vehicle and the account information also have been displayed at the receiver side. This architecture can be utilized for both active and passive on-board unit (OBU) systems, although for active systems, the circuitry of the OBU is more complicated.

To realize this architecture, we allot different frequency bands to different traffic lanes, as well as to the different purposes of target tracking and data communication. With the aid of amplitude comparison and linear frequency modulation pulse compression, the target direction can be precisely determined and the resolution in the radial direction can be 40 cm. This needs a 400-MHz bandwidth for target tracking in each traffic lane. In addition to this, if we provide 90 MHz for data transmission and two 5-MHz guard bands, then the bandwidth required by each traffic lane is 500 MHz For a four-lane highway, we need a total of 2-GHz bandwidth, say, from 89 to 91 GHz. With a 40-cm resolution, it is not difficult to distinguish two cars closely in tandem Therefore, it is necessary to collect radar images of different types of vehicles by measurement in advance in this frequency range.

This also shows that how a short message will be sent to the owner's mobile by using GSM regarding the amount detected for crossing a lane and it will be shown that no amount will be debited if the vehicle returns within 24 hrs.

However, with such high resolution, we can also distinguish the signals reflected from different parts of a vehicle.

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