Development of Real-Time Propagation Measurement System for Electric Toll Collecting (ETC) System

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ABSTRACT

In the early deployment of electric toll collecting (ETC) system, multipath interference has caused the malfunction of the system. Therefore, radio absorbers are installed in the toll gate to suppress the scattering. This paper presents a novel radio propagation measurement system to identify the individual scattering object and the power intensity of the ETC gate in real time.

1 INTRODUCTION

In Japan, electric toll collecting (ETC) system in the highway has been introduced from 2001 and currently installed in around 70 % of the toll gates. In the early deployment of ETC system, multipath interference has caused the malfunction of the system. Therefore, electromagnetic absorbers are installed on some objects, such as canopy, in the toll gate to suppress the scattering. Thanks to the electromagnetic absorbers, the malfunction significantly decreased but the periodical investigation into the corrosion is always required for the maintenance and replacement after the installation. Since the measurement has been taken only for the power of the combined signal at receiving points, the sufficient examination has not been carried out.

We have studied the identification of the propagation paths using digital signal processing with array antennas to investigate the multipath propagation mechanism precisely [1, 2] In previous studies, the measurement method using a vector network analyzer (VNA) and X-Y positioner was employed. However, it was not applicable in the toll gates that have been already opened for traffic because it was generally required to close the toll gates.

This paper proposes a novel radio propagation measurement system for the ETC gates. The most significant feature of this system is that the measurement can be made on the vehicle passing through the gates using the real ETC signal transmitted from the ETC roadside station, thus there is no need to close the toll gates. This system can identify the individual scattering object and the power intensity of the ETC gate with 3-D visualization as well as the spatial power distribution in real time. In this paper, the measurement principle and the developed system will be described. The evaluation by the field experiment will be presented as well.

2 MEASUREMENT SYSTEM

The signal processing in this system was implemented basically on Tokyo Tech MIMO software radio testbed system [3]. It consists of eight channels of receivers, ADCs, 5 large scale FPGAs for realtime processing and the buffer memory, and CPU operated by Microsoft windows system on which the developed measurement software is running. The eight element uniform antenna array is employed with two dummy elements at both end of the array and each element is made by a circularly polarized microstrip. The ETC signal received in the antenna array at RF frequency of 5.8 GHz is downconverted into low IF in the receivers. Then the IF signals are synchronously sampled by ADCs and stored in the memory implemented on FPGAs. The data processing is carried out by software on CPU. The signal and system specifications are presented in Table 1 [4]

Table 1: System specification

Signal　ARIB-T75)	
Modulation	ASK split phase coding, 1024 k symbol/s
Carrier frequency	D1:5.795 GHz, D2:5.805 GHz, BW = 4.4 MHz
Rx power range	$-39.6 \sim -60.5$ dBm, -70.5 dBm (threshold)
Array geometry	8 element uniform linear array
Element spacing	25.77 mm (0.5 wavelength)
Antenna element	Circularly polarized MSA
RF frequency	$5.470 \sim 5.875$ GHz
Bandwidth	40 MHz
Sampling frequency	80 MHz
Quantization bit	14 bit
FPGA	Xilinx Virtex-II 2 M gate $\times$ 5
FPGA memory	about 28 k sample/ch

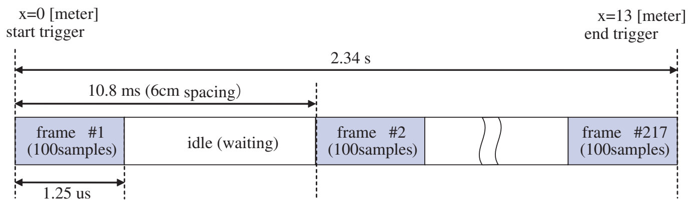


Figure 1: Capturing flow of the burst frame data (the length of the measurement area: 13 m)

3 MEASUREMENT METHOD

In the measurement, this system captures the data in burst-wise manner at each time frame in a moving vehicle. The vehicle loading this system usually passes through the toll gate at constant speed of 20 km/h. In the measurement, the laser sensor is used to trigger for the start and end positions of the measurement and the system captures the data at every equi-time interval along the running path until the end-trigger is detected. The data capturing unit was implemented on FPGAs and the capacity is 28K samples per channel for single measurement. Fig. 1 shows a burst frame example for the length of the measurement area, 13 meters, where the single frame includes 100 samples for averaging. The data is usually captured at any arbitrary asynchronous timing to the ETC signal transmission. That means that the signal captured at valid timing should only be used.

After captured passing through the gate, the signals are converted into complex signals in a baseband processing part. The 1-D beamforming on the plane including the axis of the antenna array and the source direction is computed with the estimated correlation matrix at every observation point. In order to reduce the sidelobe effect of the uniform beampattern, we employed the hamming window function in which angular resolution is nearly 20 deg at around bore sight direction.

4 SCATTERER INDENTIFICATION WITH 3D VISUALIZATION

Because this system uses a real ETC signal, the beamforming toward the moving direction of the vehicle is not available. Therefore the measurement varying the observation point was taken into consideration. In ETC gate environment, propagation mechanism including specular reflection, edge diffraction, corner diffraction and non-specular scattering as well as direct wave can be considered. However, in general, the other paths than direct and specular reflection paths are negligible. In the specular reflection, the image method can be applied to the determination of the equivalent source location that can be found by various measurement data at different positions in the same manner as the direct waves.

Figure 2 shows the coordinate system assumed in this measurement where the origin denotes the starting point of the measurement and the vehicle moves along the x-axis. When the equivalent source location can be represented by (x_0, y_0, z_0), the direction of arrival (DoA) at the location x is denoted by $\theta_0(x)$. This system computes the 1-D beamforming with an eight-element linear antenna array. The

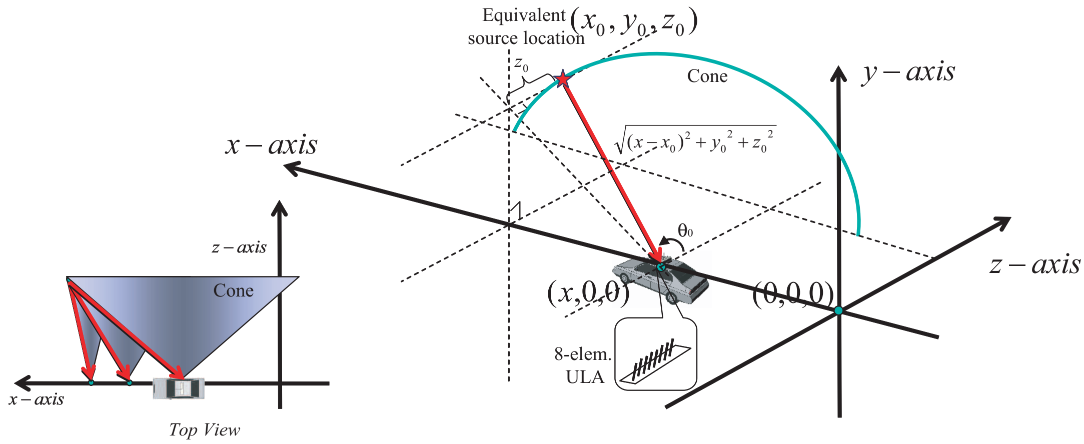


Figure 2: Coordinate system

power intensity distribution for the DoA along x-axis can be obtained by the beamforming processing.

Equivalent sources at (x_0, y_0, z_0) exist on the cone and the observation point is its vertex as shown in Fig. 2. If the equivalent source can be uniquely determined, we can identify the scattering point by tracing the peaks on the beamforming results and approximating to the curve from the relation of $\theta_0(x) = \cos^{-1}\frac{z_0}{\sqrt{(x-x_0)^2+y_0^2+z_0^2}}$. However, this method is applicable only if the size of the lit zone is sufficiently long.

Therefore, this paper proposes the scattering object identification method using 3-D visualization of beamforming results that include the signal power intensity at any direction along the observation points. An easy way to apply the beamforming results is producing a spherical beampatterns that express the corresponding power intensity by its transparency in a cone shape on its surface. It means making any parts of the surface transparent when the power is higher than a threshold value and making them colored otherwise. When producing the spherical beampattern, the threshold level should be appropriately selected. The spherical beampatterns is converted to VRML (virtual reality modeling language) with the 3-D model of the toll gate and the VRML viewer is introduced for manual identification by human eye keeping the viewpoint at the center of the spherical beampattern. It can be also thought to use the pictures of the panorama view of the gate taken synchronously to the data capturing by a fast camera instead of 3-D model of the toll gate.

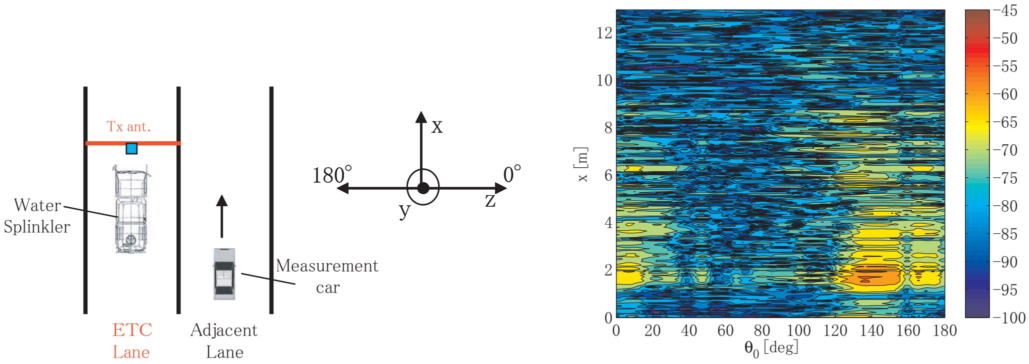
5 MEASUREMENT EXAMPLES

Figure 3 presents the measurement results on the adjacent lane in case of water sprinkler exits in ETC lane. The length of the measurement area was 13 m and the transmitter antenna location in the ETC lane was $x = 8$ m from the start point of the measurement. As shown in Fig. 3(a), the vehicle with this system carries out the measurement passing through the toll gates. Fig. 3(b) shows the contour plot of the beamforming pattern that provides the power intensity distribution. From this results, we can find large leak power about -55 dBm to the adjacent lane caused by the reflection of the water sprinkler at around $x = 2$ m and $\theta_0 = 140$ deg. It means that the malfunction can occur by this leaked signal because the threshold power level in the ETC receiver operation is prescribed by -70.5 dBm.

The results of the scattering object identification using 3-D beampatterns are shown in Fig. 4. The threshold level in producing the spherical beampattern was set by the lower bound of the ordinary receiving power, -60.5 dBm. It can be seen that the water sprinkler is identified as a scattering object and the power intensity is also easily found.

6 SUMMARY

This paper proposes a novel radio propagation measurement system useful for the ETC gates without closing the gate. The measurement can be made on the vehicle passing through the gates using real ETC signal transmitted by ETC base station. This system can identify the individual scattering object and the power intensity of the ETC gate as well as the spatial power intensity distribution in real time.



(a) Measurement situation (b) Power intensity distribution [dBm]

Figure 3: Measurement results on the adjacent lane in case of water sprinkler exits in ETC lane.

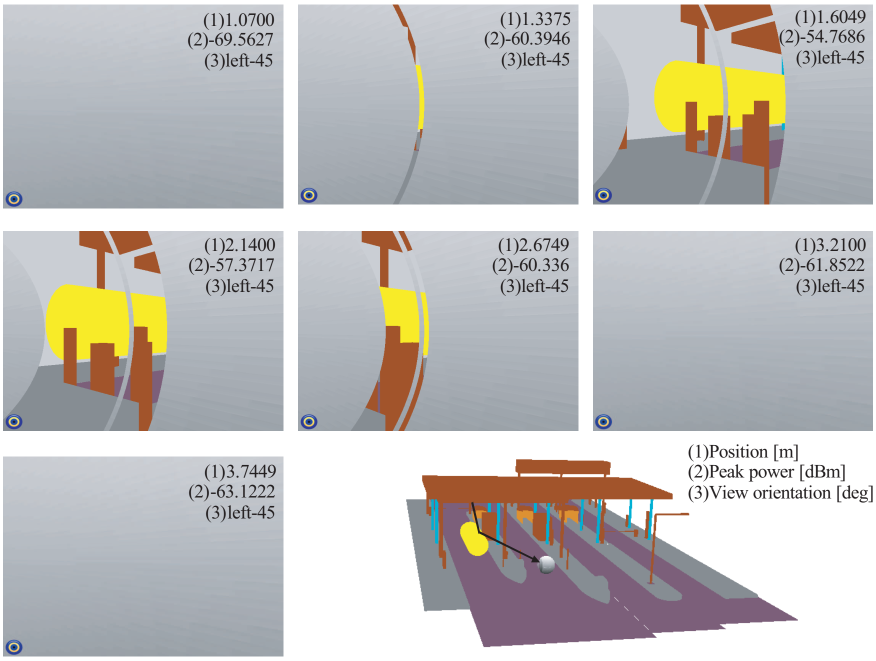


Figure 4: 3-D visualized results in VRML viewer

Moreover, the validity of the system was verified by the field experiment.

REFERENCES

[1] T. Iwata, Y. Wakinaka, and J. Takada, "Experimental Identification of Undesired Propagation Paths for ETC," *2nd International Workshop on ITS Telecommunications (ITST2001)*, pp. 131-136, Yokosuka, Japan, 2001.

[2] K. Haneda, J. Takada, T. Iwata, and Y.Wakinaka, "Experimental Determination of Propagation Paths for the ETC System – Equipment Development and Field Test –," *IEICE Trans. Fundamentals*, vol. E87-A, no. 11, pp. 3008–3015, 2004.

[3] K. Mizutani, K. Sakaguchi, J. Takada, and K. Araki, "Development of MIMO-SDR Platform and Its Application to Real-Time Channel Measurements," *IEICE Trans. Communications*, vol. E89-B, no. 12, pp. 3197–3207, 2006.

[4] "Dedicated Short-Range Communication System," *ARIB Standard*, ARIB STD-T75, Association of Radio Industries and Businesses, 2001 (in Japanese).