

# Evaluation of Connected Vehicle Technology for Concept Proposal Using V2X Testbed

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Connected vehicles that can wirelessly interact with the environment will become popular as they support safe and comfortable driving and offer improved functionality, security, and services to passengers. We have been evaluating and testing in-vehicle devices and infrastructure equipment in a realistic environment utilizing a testbed for concept proposals. This paper describes the features of the testbed and its application to the performance comparison of intelligent transport system (ITS) radio communications and the evaluation of vehicle-to-infrastructure cooperative systems.

Keywords: testbed, connected vehicle, ITS radio communication system, vehicle-to-infrastructure cooperation

## 1. Introduction

In recent years, thanks to progress in information-communication technology, intelligent transport systems (ITS) have improved and thus increased the safety, transport efficiency, and comfort of road traffic. Furthermore, safe and comfortable driving support systems are going to be increasingly introduced using dedicated communication media, such as vehicle-to-infrastructure and vehicle-to-vehicle communications. These communicate wirelessly with equipment installed in nearby vehicles and roadside infrastructure and acquire information on, for example, vehicles approaching from outside the field of vision and traffic signal lighting at intersections.

Communications dedicated to ITS are used in some cases and mobile phone data communications (hereafter referred to as “cellular communications”) are used with an eye to integration with the cloud, security, artificial intelligence, and other information technologies in some other cases. “Connected vehicles\*1”) are cars that are equipped with various communication functions and thus can serve as advanced information communication terminals by connecting with the Internet, and are now actively being developed.

With this background, Sumitomo Electric Industries, Ltd. has commercialized servers for road traffic control systems that, for example, control traffic signals as well as for cellular communication systems, thus helping to spread the basic technology for connected vehicles. Inside vehicles, the Company has developed in-vehicle communication and wiring harness technologies that transmit signals, and conducts research and development of in-vehicle wireless radio equipment in order to achieve highly functional in-vehicle and roadside infrastructure systems by integrating communications inside and outside vehicles.

The authors have built an infrastructure environment at our Yokohama Works testbed\*2 in cooperation with our Information Network R&D Center (formerly Infocommunications and Social Infrastructure Systems R&D Center), which has been engaged in developing roadside communication equipment. We are already using the testbed to verify radio communication performance and

connected technologies. This paper reports the setup of the testbed and its application.

## 2. Development Flow and Testbed Positioning

In developing and evaluating in-vehicle devices, it is necessary to equip them in real vehicles in an environment simulating actual traffic in order to identify issues and study ways to resolve them. As shown in the development flow in Fig. 1, development devices are initially equipped in actual vehicles, evaluated and verified, and then the results are fed back to the development process.

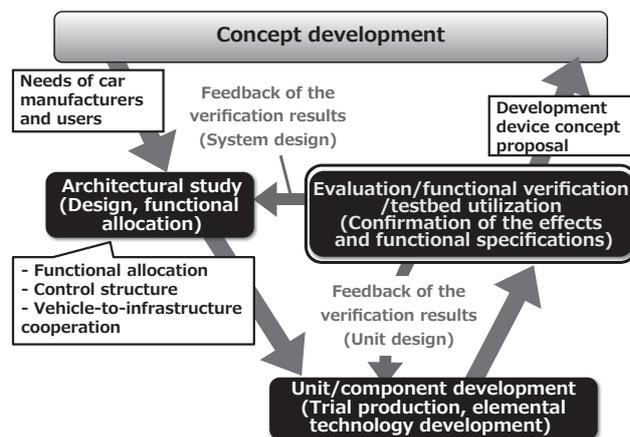


Fig. 1. Flow of concept development

The aim is to define the concept including in-vehicle devices and infrastructure devices while iterating the development and evaluation cycle, then to propose the concept to the customer and eventually finalize the concept. A testbed is used for this evaluation and functional verification.

### 3. Outline of the Testbed and Evaluation Vehicles

Figure 2 shows the main facilities of the testbed. The traffic infrastructure and evaluation vehicles provided in the testbed are explained in the following sections.

#### 3-1 Roadside equipment for the ITS radio communication system

The ITS radio communication system achieves vehicle-to-vehicle, vehicle-to-infrastructure, and infrastructure-to-infrastructure communications. In the testbed, 760 MHz band roadside equipment for the ITS radio communication system<sup>(1)</sup> (hereafter referred to as the “ITS radio roadside unit”) is installed. Information can be transmitted to, for example, nearby vehicles through the ITS radio roadside unit based on the information obtained by the camera-type vehicle detector, which is explained below.

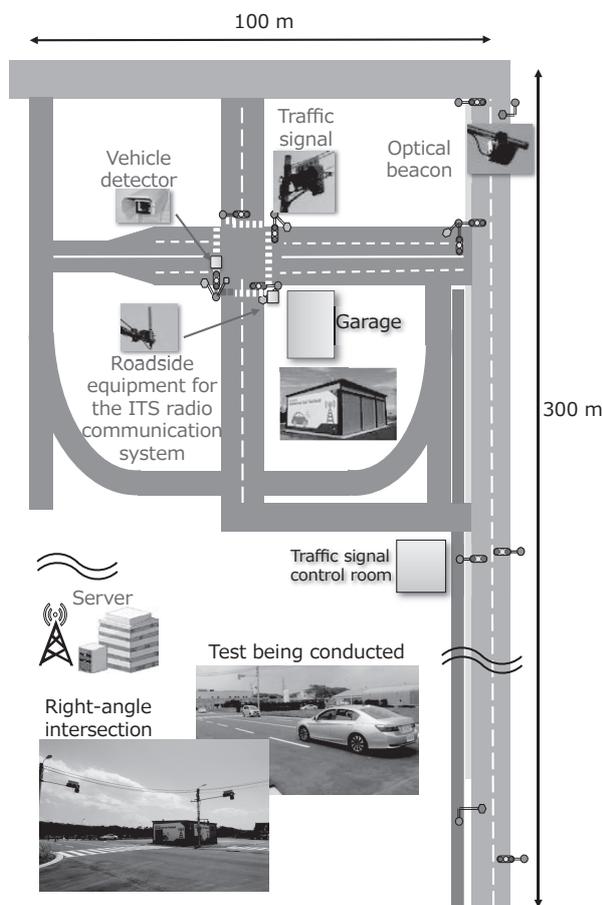


Fig. 2. Main facilities of the testbed

#### 3-2 Roadside sensor

##### 3-2-1 Camera-type vehicle detector

The camera-type vehicle detector can measure and monitor the traffic stream and detect, for example, whether there are vehicles in a particular lane and the distances to the vehicles.

##### 3-2-2 Advanced optical beacon

An optical beacon is a light emitting and receiving device using near-infrared light that is installed on the

roadside and allows two-way communications with in-vehicle devices. Probe information, including the time taken for the vehicle to pass between optical beacons, is transmitted from the in-vehicle device to the optical beacon. Traffic information, including traffic congestion information and travel time, is transmitted from the optical beacon to the in-vehicle device. In the case of an advanced optical beacon,<sup>(2)</sup> route signal information is also included, which allows the provision of functions reflecting information on the lighting cycles of traffic signals and the distances between traffic signals (such as traffic signal waiting time guidance and traffic signal passing support) to the vehicle side. Several advanced optical beacons are installed in the testbed.

#### 3-3 Running test course

The testbed has a running test course of about 100 m × 100 m, including a right-angle intersection, curves, lane-merging, branches, and a reduction of traffic lanes. There is a straight main road of about 300m length with several traffic signals and a signal control room.

#### 3-4 Evaluation vehicles

In order to verify in-vehicle devices, it is important to reveal issues through evaluation at the testbed using test vehicles. Such vehicles are equipped with radio equipment that communicates with a server via cellular communications, ITS equipment that enables communications with roadside units, and an advanced optical beacon. Figure 3 shows the flow of information between the evaluation vehicle and the nearby area.

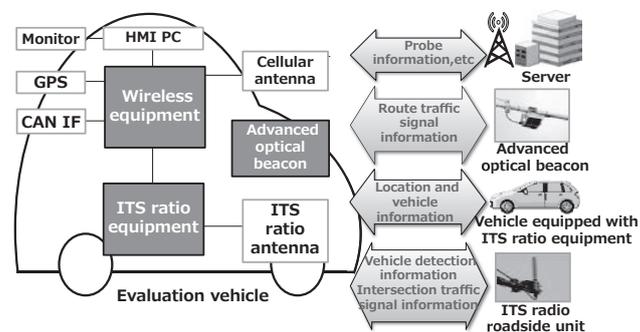


Fig. 3. Flow of information between the evaluation vehicle and the nearby area

### 4. Examples of Testbed Utilization

#### 4-1 Comparative verification of performance of ITS radio communication system

ITS radio communication systems have been used in Japan as ITS safe driving support systems using the 760 MHz band. In contrast, use of the 5.9 GHz band is going to be legislated in Europe and North America and therefore performance had to be evaluated at both frequencies in view of overseas development. Since the 5.9 GHz band are not used for ITS in Japan, the authors decided to acquire an experimental station license in a nearby frequency band of 5.8 GHz (used for non-stop electronic toll collection (ETC) systems) and to conduct the evaluation in that band to predict performance in the 5.9 GHz band.

The frequencies used for radio communications have differing characteristics; generally the radio wave propagation attenuation is less and the amount of diffraction is more for a low frequency (760 MHz band) than a high frequency (5.8 GHz band). Initially, it was decided to equip wireless equipment on vehicles to make comparative measurements and quantitatively compare these characteristics.

In order to visualize the radio wave propagation status at the testbed, the transmission output of the ITS wireless equipment at the two frequency bands was set to the same value and the radio field intensity was measured while the vehicle on the transmission side was stopped and the vehicle on the reception side was moving. Figure 4 shows a radio field intensity map created based on the measurement results.

The radio wave propagation attenuation is about 18 to 26 dB larger for the 5.8 GHz band, which is consistent with the theory.

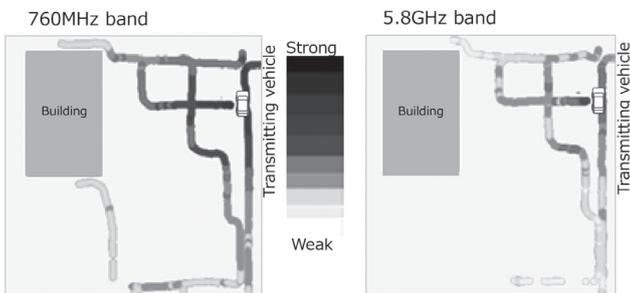


Fig. 4. Example of the radio field intensity map at the testbed

Subsequently, it was decided to compare the diffraction performances of radio waves by using the service with an actual ITS radio communication system as an example. As shown in Figure 5, using the example of the service of the head-on collision prevention support system of the wireless ITS safe driving support system<sup>(3)</sup> studied in the Ministry of Internal Affairs and Communications as a reference, measurements were made in an environment with a shielding obstacle (building) present.

Figures 6 and 7 show the results of the comparison of radio field intensities and packet delivery ratios, respectively.

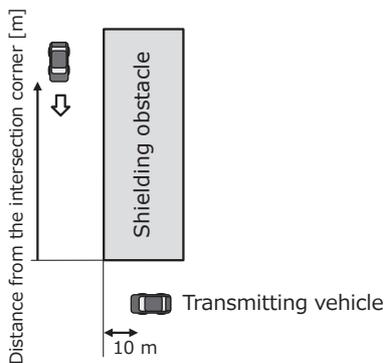


Fig. 5. Example of services of the head-on collision prevention support system

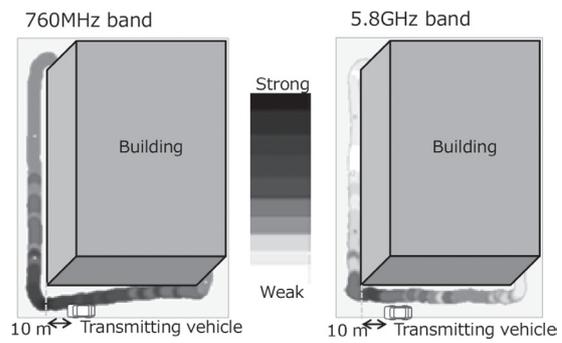


Fig. 6. Example of diffraction comparison (Radio field intensities)

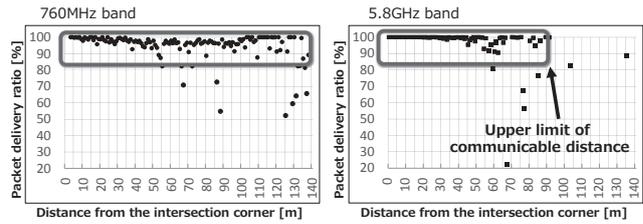


Fig. 7. Example of diffraction comparison (Packet delivery ratios)

Consequently, it was found that the distance of radio waves from the transmitting vehicle diffracted around the corner of the building was longer for the 760 MHz band. Comparing these with the test results for the wireless ITS safe driving support system of the Ministry of Internal Affairs and Communications under the same conditions, both results almost coincided with each other, suggesting that the measurements were reliable.

To compare and verify the performances this time, the evaluation vehicles were designed to save all of the transmitted and received data in the designated format. In addition, the system was designed so that, when measurement conditions such as the weather, temperature, traffic volume, time, and vehicle speed changed, the measurement results were accumulated to enable comparison of the repeatability of communications as well as the influence of the surrounding environment. In addition, an analysis tool to confirm the communication information in real time was developed, making it possible to immediately study to resolve issues.

In the future, measurement results under various environments will be accumulated to predict how radio waves are affected by buildings and structures, and the results will be reflected in the design of in-vehicle devices and antennas.

#### 4-2 Functional verification of application of vehicle-to-infrastructure cooperative cellular communications

As an example of the evaluation of in-vehicle wireless radio equipment, an application of vehicle-to-infrastructure cooperative cellular communications from the vehicle using probe information is shown in Fig. 8. On the vehicle side, using vehicle behavior such as abrupt steering and braking as triggers, the image from the in-vehicle camera is recognized in a simplified manner. When, for example, the image suggests a falling object, location information and images from the in-vehicle camera are transmitted to the

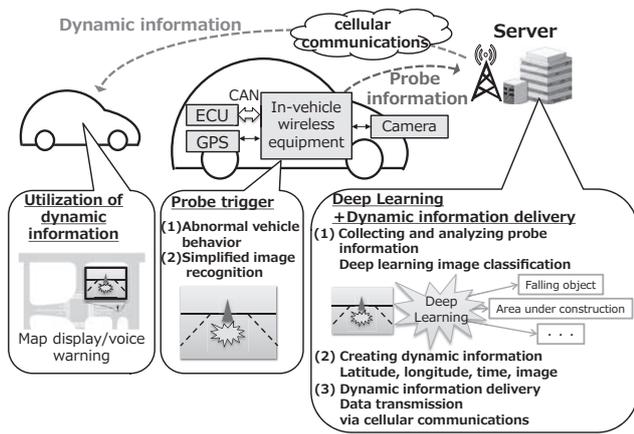


Fig. 8. Example of applications of vehicle-to-infrastructure cooperative cellular communications

server as probe information using cellular communications. On the server side, the image is classified in detail through deep learning\*3 and it is analyzed to determine what the object is or means (e.g., an object lying on the road, area under construction, etc.) based on the image transmitted from the vehicle. Based on the analysis results, dynamic information, which includes the location, time of day and image, is created and delivered to nearby vehicles (including following vehicles) via cellular communications.

To set a vehicle behavior of abrupt steering as a trigger, the controller area network (CAN) messages of the vehicle was collected using the running test course of the testbed to verify whether abrupt steering could be detected. The steering angle and lateral acceleration were originally used to detect it; however, there were many false detection cases in the trigger detection results and the expected results could not be obtained. Consequently, based on the results of studying accumulated running data of actual vehicles, it emerged that a vehicle behavior of abrupt

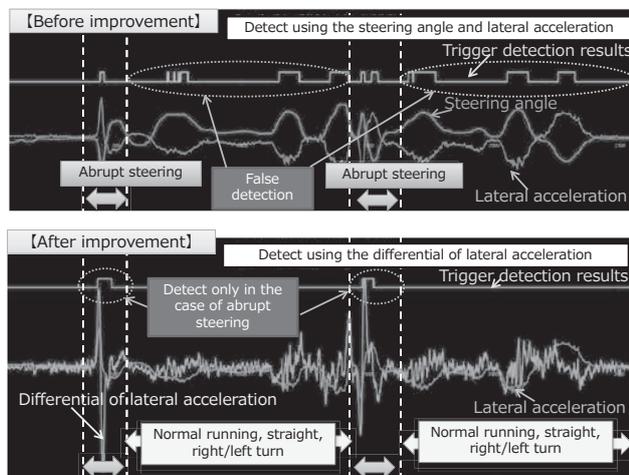


Fig. 9. Example of setting the conditions to detect abrupt steering

steering could be accurately detected if the differential of the lateral acceleration was used. Figure 9 shows the details before and after improvement. In this manner, the system with the cooperation of the in-vehicle wireless radio equipment and the server can be verified, which the authors will use to propose future concepts.

## 5. Conclusion

This paper described an outline of the testbed and evaluation vehicles as well as examples of using them to compare the performance of ITS radio communication systems and verify the functions of applications of vehicle-to-infrastructure cooperative cellular communications. In the future, the number of sensors (such as cameras and millimeter-wave radars for pedestrians) on the infrastructure side will increase for safer and more comfortable driving, and broader band data transmission and reception will be increasingly needed for communications. In developing connected technologies to meet these demands, the authors will feed back the results of verification by looking at the whole system, including the road side and vehicle side, at the testbed and use the feedback results to develop future concepts.

### Technical Terms

- \*1 Connected vehicle: A vehicle that has functions as an information communication terminal. A connected vehicle is expected to create new value by acquiring various data, such as vehicle and nearby road conditions, by sensors and accumulating and analyzing the acquired data.<sup>(4)</sup>
- \*2 Testbed: Generic term for a test platform similar to the actual operating environment used for large-scale system development. In this paper, the testbed refers to the facilities including the traffic infrastructure and the running test course in Yokohama Works of Sumitomo Electric for verifying connected technologies.
- \*3 Deep learning: Machine learning using a multilayer neural network. Deep learning allows automatic design of characteristics corresponding to the inputs and outputs designed by engineers without needing to extract the amount of characteristics. In the image recognition contest held in 2012, deep learning attracted attention for its overwhelming recognition accuracy.

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