Evaluation of 700 MHz Band Radio Resource Allocation Algorithm and Installation Operation of Roadside Units

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In the urban area where the wireless roadside units of 700-MHz band intelligent transport systems (ITS) are densely installed, an operation method is required to install the units as many as possible by efficiently allocating limited radio resources without interference. This paper evaluates the radio resource allocation algorithm that utilizes simulation and proposes an installation and operation method devised based on the evaluation.

Keywords: 700 MHz band, ITS, simulation, radio resource allocation

1. Introduction

In the automotive industry, research and development are under way in many parts of the world on connected and autonomous vehicles (CAV) and electric cars. In the area of CAV are intelligent transport systems (ITS). ITS uses wireless communications between users, vehicles, and infrastructure to solve road traffic issues, such as accidents and traffic congestion. Active efforts are being directed towards the development of ITS.[1),(2] Specifically in Japan, a plan to allocate the 700 MHz band to ITS wireless communications was announced in December 2011. Relevant standard communication specifications were issued (ARIB STD T-109). As a case of ITS utilization, a vehicle-to-infrastructure/vehicle (V2I/V2V) communication system has come into the stage of practical use. For example, by way of wireless communications between base stations installed along a road (roadside units) and vehicles (in-vehicle units), this system enables car drivers to obtain traffic information otherwise difficult to recognize by the eye or in-vehicle sensors. However, the frequency band for 700 MHz band wireless communications assigned to ITS is limited to 10 MHz. Consequently, where many ITS wireless roadside units (RSUs) that use the same frequency band are placed in an area, interference between RSUs can occur relatively readily. For this reason, along with the widespread use of ITS, concerns have arisen that a shortage of radio resources could occur unless RSUs are installed efficiently. Therefore, methods have been explored[(3),(4)] to allocate radio resources efficiently to RSUs. However, to install and operate RSUs in practice, it is also important to consider ease of operation in light of new installations of RSUs increasing with time, in addition to efficient allocation of them.

This report compares and evaluates two major algorithms proposed as radio resource allocation methods for RSUs, using a multi-agent simulator.[(5)] Moreover, the RSU installation capacity is verified, simulating the actual road situation in the Ginza area in Chuo Ward, Tokyo, envisioned to have a high density of installed RSUs. This report proposes an innovative RSU installation and operation method considering two aspects: 1) regularity in resource allocation (ease of management) and 2) the maximum number of installable RSUs.

2. Prerequisites

2-1 Radio resources

This report defines radio resources by the communication band time-sharing method proposed in the 700 MHz Band Intelligent Transport Systems: Guidelines for experimental communications between infrastructures (I2I)[(6)] (ITS FORUM RC-012) (Fig. 1). This method uses a data transmission period (100 ms), designated as a "frame" as a unit of periodic control, for V2I/V2V communications and time-shares the frame at predetermined intervals. More specifically, in one frame, RSUs handle up to 16 V2I communication durations (radio slots). V2V communication is established at other timing points. Moreover, ITS FORUM RC-012 explores advanced driving assist, which is achieved by communicating signal light information between RSUs (I2I communications). For that purpose, specific radio slots are further time-shared for I2I communications for multiple RSUs to share them. When installing RSUs, one challenge is how to allocate 16 radio slots easily and efficiently.

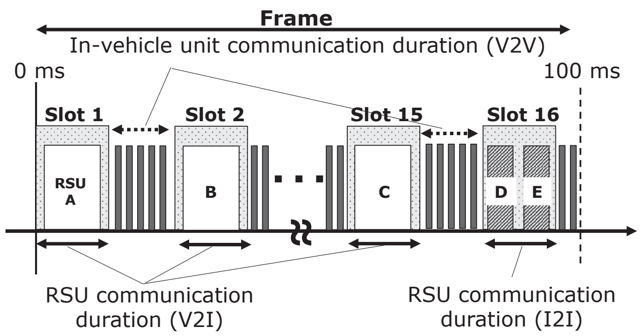

Fig. 1. ITS radio communication method (700 MHz band)

2-2 Radio resource allocation algorithm

The following is a brief introduction to the two major radio resource allocation algorithms evaluated for this report. The first is known as the prioritized station-based greedy (PSG) algorithm. Each time RSUs are installed, the

PSG algorithm makes interference relations clear between all RSUs and allocates interference-free radio slots sequentially. The second is known as the vector-based cell cover (VC) algorithm. For its allocation steps, the VC algorithm begins with dividing an area envisioned for the installation of RSUs into a mesh of cells of a particular size, as shown in Fig. 2 (a). Subsequently, the VC algorithm allocates radio slots to each cell and draws up a VC-based allocation map, as illustrated in Fig. 2 (b). This allocation is made in such a manner that when installing one RSU in each cell, no interference occurs between RSUs and the minimum number of radio slots is allocated. Since the number of RSUs installed in a cell is not limited to one, unused radio slots not allocated to any cell are reserved as extra resources. In the case that a cell has a second RSU installed, extra resources reserved when drawing up the VC-based allocation map will be allocated.

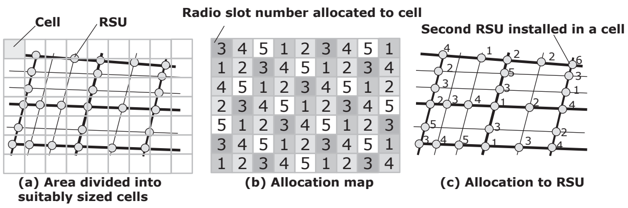

Fig. 2. Example allocation by VC algorithm

3. Simulation Experiment (Grid-Like Road Situation)

3-1 Simulation conditions

The two radio resource allocation algorithms were compared with each other and evaluated via simulation to clarify their features. The transmission data size and other wireless communication conditions for RSUs were identical with the technical conditions studied[7] for an advanced version of the 700 MHz band ITS. The principal four road layout patterns evaluated in the study[7] each were used for the evaluation (Fig. 3).

Road layout patterns 1, 2, and 3 represent a grid-like road layout respectively at uniform 400 m, 300 m, and 200 m intersection intervals. In these patterns, intersection networks are formed with each network comprising five RSUs connected via I2I communication in the shape of a cross.

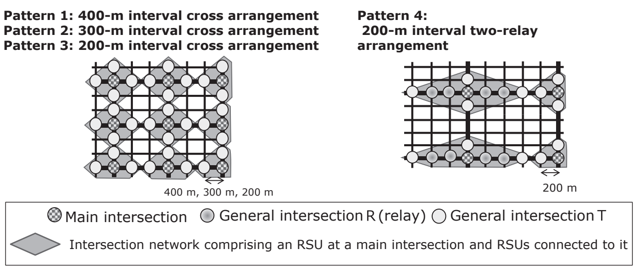

Fig. 3. Road layout pattern

Road layout pattern 4 in the aforementioned study[7] assumes that RSUs have the densest communications traffic. This pattern has four RSUs (at general intersections R in Fig. 3) that relay adjacent RSUs in their intersection network.

This paper defines a main intersection as an intersection of arterial roads or the like and the RSU that is at the center of an intersection network and is connected to a traffic control center. The RSU at the main intersection (main intersection RSU) differs from RSUs installed at other intersections (general intersection RSUs) in that it transmits a larger amount of information. This definition somewhat deviates from the definition of the traffic control term *main intersection*. The main intersection used in this paper was modeled according to the amount of transmitted information.

3-2 Comparison and evaluation results

Using the above-mentioned road layout patterns 1, 2, and 3, the PSG and VC algorithms were compared with each other and evaluated. The results are shown in Fig. 4. The number of installed RSUs increasing with time is plotted along the x-axis. Generations are defined for convenience sake on envisioned patterns of progress in installation. Figure 5 gives an example. The 1st to 3rd generations are installed at main intersections. The 4th to 6th generations are installed at general intersections. The 7th generation is installed at intersections along sub-arterial and arterial roads. The 8th generation fills up all intersections. The number of required radio slots is plotted along the y-axis.

The comparison results reveal that in road layout patterns 1, 2, and 3, the number of required radio slots is

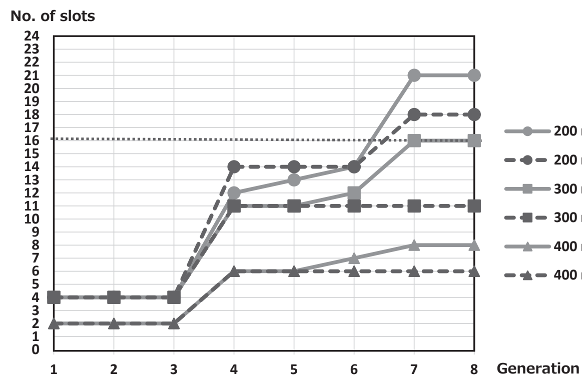

Fig. 4. Allocation results for crossroads intersection scenario

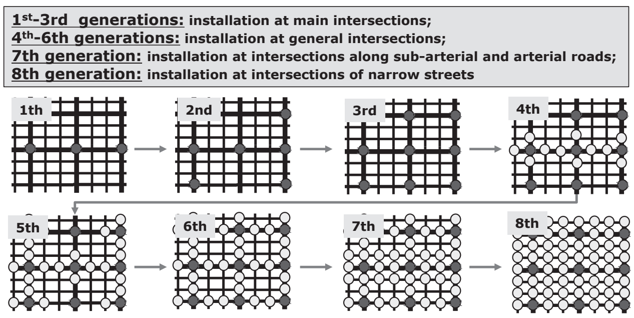

Fig. 5. RSU installation scenario

fewer with the VC algorithm than with the PSG algorithm, while in road pattern 3, the upper limit to the number of radio slots (16) was exceeded. Meanwhile, a comparison of the required numbers of radio slots of generations staying below the upper limit shows that the PSG algorithm is advantageous. Next, Fig. 6 illustrates the results for road layout pattern 4.

The results presented in Fig. 6 reveal an increase in the number of required radio slots (16) for VC-based allocation in comparison with the results for road layout pattern 3 shown in Fig. 4. The cause of this increase lies in the need to relay information sent from the RSU ahead, in addition to usual I2I communications. In contrast, for PSG-based allocation shown in Fig. 6, the number of radio slots is fewer than with VC-based allocation up to the 7th generation. The reason for this result is as follows. In the road layout pattern illustrated in Fig. 6, data-relaying RSUs are placed between main intersections. Therefore, compared with road layout pattern 3 shown in Fig. 5, the road pattern shown in Fig. 6 results in wider intervals between main intersections. Hence, it is not necessary to consider interference between main intersection RSUs. According to these results, the features of the allocation algorithms are summarized below.

(1) For wider intersection intervals (400 m/300 m), the VC algorithm is more advantageous than the PSG algorithm due to a fewer number of radio slots required for allocation.

(2) For narrower intersection intervals (200 m), the PSG algorithm is more advantageous than the VC algorithm due to a fewer number of radio slots required for allocation.

However, narrow intersection intervals are subject to reaching the RSU installation capacity, resulting in some intersections being not provided with any RSU.

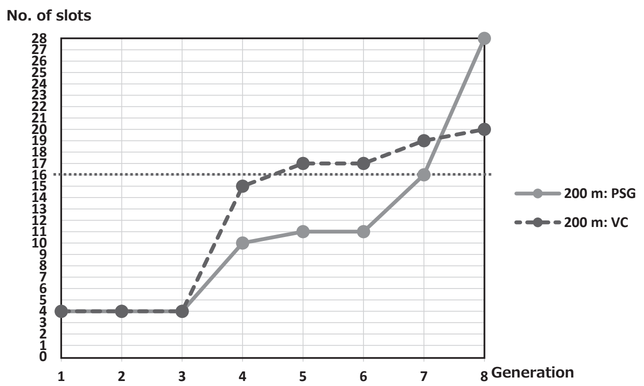

Fig. 6. Allocation results for 200-m interval crossroads intersection (data relayed) scenario

4. Simulation Experiment (Actual Road Situation Simulated)

With knowledge that the intervals of main intersection RSUs have an influence on the number of required radio slots, we measured, via simulation, the RSU installation capacity for individual main intersection defining patterns envisioned to be in operation in an actual road situation.

4-1 Simulation conditions

The road layout in Ginza was represented via simulation. It was assumed that RSUs would be installed at intersections with traffic lights installed as of September 2017, and sequentially starting from intersections of higher road traffic volumes. Main intersections were defined in two assumed patterns.

Main intersection defining pattern 1: intersection of arterial roads

Main intersection defining pattern 2: intersection of arterial roads or of an arterial road and a sub-arterial road

Using these two patterns, allocation algorithms were compared and evaluated as to how the RSU installation capacity would change.

4-2 Radio slot allocation results

Figure 7 presents the results for main intersection defining pattern 1. VC-based allocation reached the RSU installation capacity when all arterial road intersections were provided with RSUs (totaling 12). PSG-based allocation turned out to enable all the target intersections to be provided with RSUs (totaling 47). Figure 8 shows the results for main intersection defining pattern 2, in which VC-based allocation reached the RSU installation capacity when RSUs (totaling 10) were installed at intersections adjacent to main intersections. PSG-based allocation reached the RSU installation capacity when RSUs (totaling 12) were installed along all arterial roads.

The results revealed that it would be possible to install RSUs at all the target intersections by PSG-based radio resource allocation, only when installing a main intersection RSU at one intersection of arterial roads.

5. Installation and Operation Planning

In light of the features of the two radio resource allocation algorithms elucidated by the evaluations described in the preceding chapters, this paper proposes an RSU installation and operation method (combined PSG/VC system) that meets the two installation and operation requirements: (1) regularity in resource allocation (ease of management) and (2) the number of required radio resources.

5-1 Combined PSG/VC system operation steps

The combined PSG/VC system in advance draws up an across-the-country VC-based allocation map comprised of uniformly sized cells. The basic installation and operation guideline is to allocate radio slots based on this map. In exceptional cases, PSG-based allocation is carried out in areas where two or more RSUs are installed in a cell. This technique uses VC-based allocation as the basic option. By doing so, it becomes easy to allocate and manage resources. Moreover, it becomes possible to further improve ease of resource allocation and management by using some standard areas established across the country. For example, the VC-based allocation map may incorporate the standard known as the quarter regional mesh[8] defined by the Ministry of Internal Affairs and Communications, which divides the land of Japan into approximately 250 m square mesh areas by latitude and longitude. Moreover, the installation and operation method achieves the maximum avail-

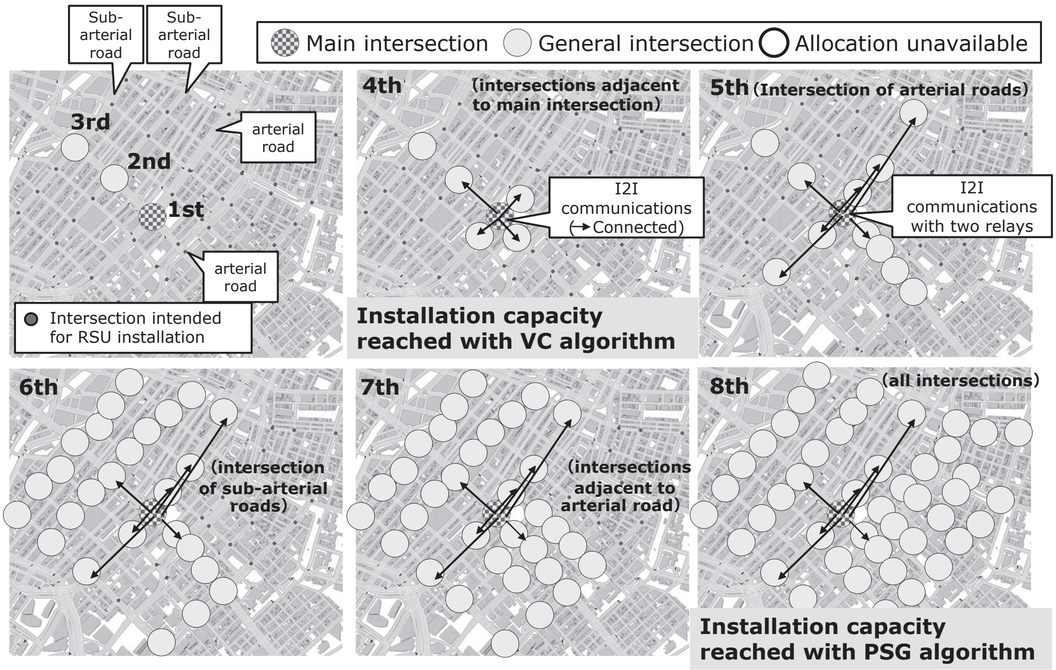

Fig. 7. Evaluation results for important intersection defining pattern 1 (intersection of arterial roads)

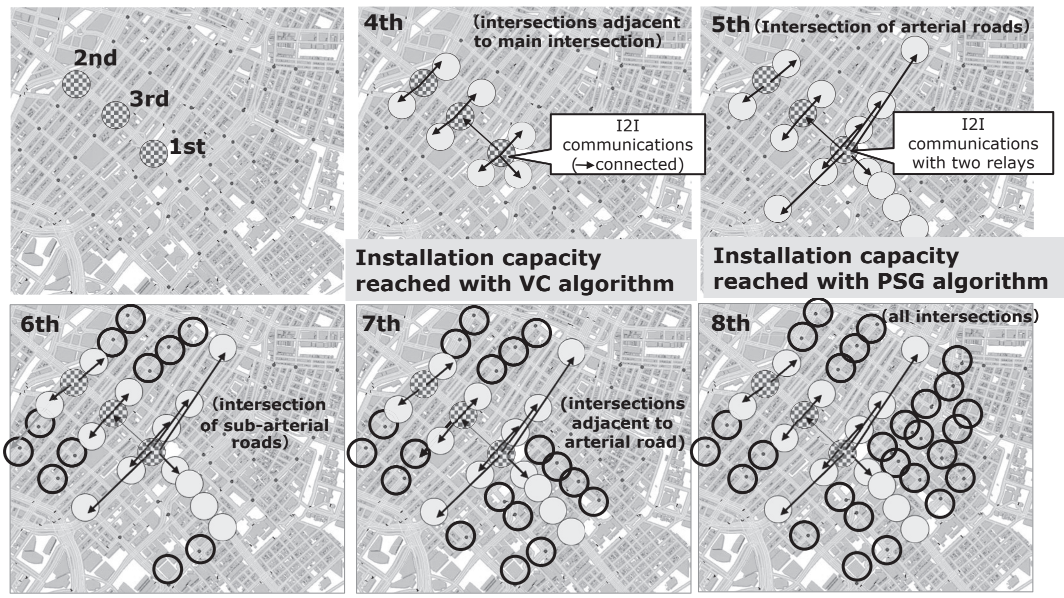

Fig. 8. Evaluation results for important intersection defining pattern 2 (intersection of arterial roads + intersection of arterial road and sub-arterial road)

able RSU installation capacity by carrying out PSG-based allocation in areas of a high RSU installation density as in a cell where two or more RSUs are installed. Figure 9 gives a concrete example of this operation.

Figure 9 (a) illustrates a final RSU installation situation in an intersection pattern. Figures 9 (b) to (f) show implementation scenarios for the combined PSG/VC system for sequential one-by-one installation of RSUs. It is a basic practice of VC-based allocation to install one RSU in one VC-based allocation cell, as illustrated in Fig. 9 (b). Figure 9 (c) gives an allocation example for an over-crowded area in which two or more RSUs are installed in a VC-based allocation cell. First, PSG-based allocation is carried out for the second RSU, as shown in Fig. 9 (c-1). Subsequently, because VC-based allocation is not available in an area where RSUs allocated by the PSG algorithm interfere with each other (interference area), a PSG area with a wider space than the interference area is defined around the cell in which the RSUs allocated by the PSG algorithm are located, as illustrated in Fig. 9 (c-2). Thereafter, when an RSU is newly installed in a PSG area, PSG-based allocation is carried out instead of VC-based

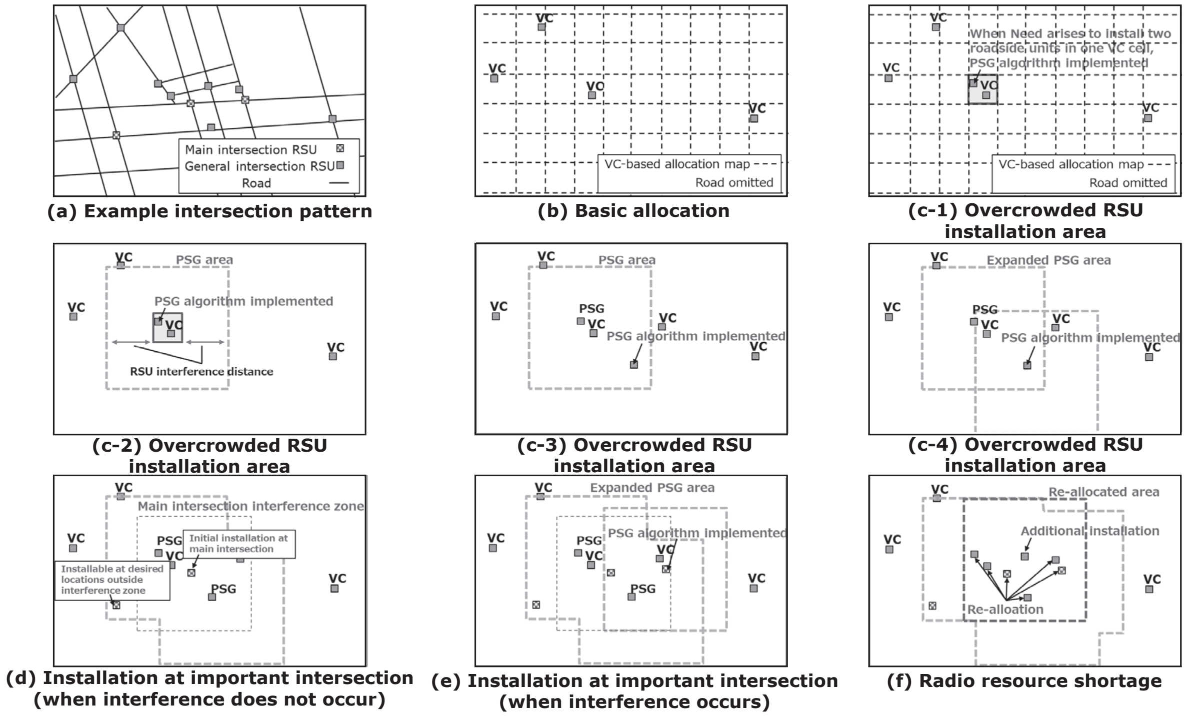

Fig. 9. Example steps followed by combined PSG/VC system

allocation, as shown in Fig. 9 (c-3). When an additional PSG-based allocation is carried out, a PSG area is defined in a similar manner, involving PSG area expansion, as represented in Fig. 9 (c-4). The combined PSG/VC system repeats the procedure illustrated in Figs. 9 (b) and (c).

Figures 9 (d) and (e) show allocation methods usable when installing main intersection RSUs. With the knowledge that the RSU installation capacity decreases radically as a result of interference between main intersection RSUs, as revealed by the results described in Chapter 4, the combined PSG/VC system avoids installing an RSU in the zone interfering with the adjacent main intersection RSUs (main intersection interference zone) to the greatest extent possible. In addition, radio slots not intended for general intersections are used. For this reason, RSUs can be installed at desired locations outside the main intersection interference zone, as shown in Fig. 9 (d). However, when the need arises to additionally install a main intersection RSU in a main intersection interference zone, it becomes necessary to expand the PSG area similarly to that above, allocating radio resources reserved for general intersections to the newly installed RSU via PSG-based allocation, as illustrated in Fig. 9 (e).

When radio resources to be allocated exceed the upper limit (16 slots), a re-allocation area is defined for the interference area of the newly installed RSU, as illustrated in Fig. 9 (f). In this area, radio resources allocated to all RSUs are re-allocated via the PSG algorithm to expand the PSG area similarly to the above-described steps.

Simulation results showed that allocation based on the combined PSG/VC system for the scenario of installing RSUs in Ginza, under the same conditions as used in the experiments discussed in the preceding chapters, enabled RSUs to be installed at all the target intersections, similarly to the PSG-based allocation results shown in Fig. 8. Consequently, the proposed technique enables radio resources to be allocated to a similar number of RSUs to that possible by PSG-based allocation even in a situation in which RSUs are densely distributed. Moreover, where RSUs are sparse, the proposed technique enables easy-to-operate VC-based allocation to be implemented.

6. Conclusion

This paper compared two major radio resource allocation algorithms, evaluated them, and elucidated their features, considering a geographic spatial situation where RSUs are expected to be installed densely in the future. Based on the results thereof, an innovative RSU installation and operation method was proposed, considering two factors: (1) ease of resource allocation and management and (2) RSU installation capacity.

The proposed technique proved itself to enable RSUs to be installed at all the target intersections by allocating resources below the upper limit to the number of slots (16) in the Ginza area, Chuo Ward, Tokyo.

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