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journal or publication title	IEICE Transactions on Information and Systems
volume	E104.D
number	4
page range	508-512
year	2021-04-01
URL	http://hdl.handle.net/10228/00008130

doi: https://doi.org/10.1587/transinf.2020EDL8088

LETTER

Transmission Control Method for Data Retention Taking into Account the Low Vehicle Density Environments*

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SUMMARY With the development and spread of Internet of Things (IoT) technology, various kinds of data are now being generated from IoT devices. Some data generated from IoT devices depend on geographical location and time, and we refer to them as spatio-temporal data (STD). Since the "locally produced and consumed" paradigm of STD use is effective for location-dependent applications, the authors have previously proposed a vehicle-based STD retention system. However, in low vehicle density environments, the data retention becomes difficult due to the decrease in the number of data transmissions in this method. In this paper, we propose a new data transmission control method for data retention in the low vehicle density environments.

key words: *Internet of Things, spatio-temporal data, local production and consumption of data, data retention*

1. Introduction

With the development and spread of Internet of Things (IoT) technologies, the number of devices connected to the Internet is increasing. According to Cisco Systems, Inc., the number of devices connected to IP networks will be more than three times the global population by 2022 [1]. Therefore, various kinds of data are now being generated from IoT devices.

From the viewpoint of data content, some data generated from IoT devices, such as traffic, weather, and disaster-related information, are highly dependent on location and time. We define such information as "spatio-temporal data (STD)." The most effective way to use STD is to provide it directly to the users from STD generation location rather than from remote server. Therefore, to realize the "local production and consumption (LPAC) of data", we need a new mechanism for distributing data based on generation place and time of STD.

In this study, we focus on vehicular ad hoc networks (VANETs) as an important network infrastructure that can achieve to support the paradigm of LPAC without supports of the Internet infrastructure. Since modern vehicles can be equipped with storage modules, computing resources, and short-range wireless communication devices, STD can be collected, analyzed, and distributed at generation place of STD by using vehicles as information hub (InfoHub).

Therefore, we have proposed a vehicle-based STD retention system as a means of distributing STD based on geographical proximity [2]. However, in this system, since all vehicles use the same communication channel, the incidence of data collisions increases when the number of vehicles increases, which in turn leads to deterioration in communication quality. In order to solve this problem, we have also proposed a method for controlling data transmission probabilities based on the density of neighboring vehicles [2]. This method assumed data retention in an environment with high vehicle density. However, since vehicle density levels are always changing due to the high mobility of the vehicles participating in the network, span of time that the vehicle density levels become low occur (for example, night). In this time, each vehicle must accelerate data transmission activities because the number of vehicles available for data transmissions is reduced.

In this paper, we propose a transmission control method for low vehicle density environments. In a low vehicle density environment, each vehicle must accelerate data transmission activities as described above, but excessive consumption of radio resources leads to degradation of communication quality. Therefore, in order to achieve appropriate data transmission control according to the situation, our propose method adjusts its transmission period based on its position relationship with neighboring vehicles [3].

2. Related Works

Maihofer proposed an abiding geocast in which all vehicles in the retention area hold the data during lifetime in the network [4]. This method, which functions without a server, has been studied recently because of no outside infrastructure is required, and a number of systems have been proposed, such as [5], floating content [6], Locus [7], and our previous work [2], [8]. In the method of [5], a vehicle exchanges navigation information to predict vehicles heading

Manuscript received June 17, 2020.
Manuscript revised November 18, 2020.
Manuscript publicized January 5, 2021.

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*The earlier version of this paper was presented at the 11th International Conference on Intelligent Networking and Collaborative Systems (INCoS-2019).

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DOI: 10.1587/transinf.2020EDL8088

into a retention area, and then delivers the data, like advertising, traffic notifications, and so on. In the Floating Content [6] and Locus [7] system, each vehicle has a data list and exchanges it with passing vehicles. Next, each vehicle determines their data transmission probability based on their distance to the center where the data was generated. As the distance from the center increases, data acquisition probabilities decline. On the other hand, when there are numerous vehicles in the vicinity of the center, channel contention occurs, and the communication quality deteriorates because all vehicles transmit data with high transmission probabilities. Furthermore, even if data can be stored in the vicinity of the place where it was generated, there is an overhead in the data acquisition process because the users acquire data by query/response type information distribution such as query transmission, data discovery, and transfer to users.

With these points in mind, we propose a novel network base capable of passively acquiring data as part of efforts to reduce overhead, while accelerating local production and consumption of data.

3. STD Retention System

In this section, we describe the assumptions, requirements, and outline of the retention system [2], and then discuss the problems we tackle in this paper.

3.1 Assumptions

In this system, STD includes not only data for an application but also retention requirements such as the center coordinates, the retention area radius R, the auxiliary area length r and the data transmission period d. The auxiliary area is an area where vehicles retaining the STD around the boundaries but outside of the retention area can contribute to improve coverage rate. Each vehicle can obtain location information using a Global Positioning System (GPS) receiver and broadcasts a beacon including a unique identifier (ID). Furthermore, all vehicles are equipped with the same antenna and transmit at equal power levels.

3.2 System Requirements

The STD retention system is to constitute an area where users can passively receive the STD intermittently transmitted from the neighboring vehicles. The STD is first transmitted only once from the information source located in the center of the retention area and spreads it throughout the retention area by InfoHub vehicles.

In this paper, we defined coverage rate as an indicator of the data retention state. The coverage rate formula is as follows:

$$Coverage\ Rate = \frac{S_{DT}}{S_{TA}} \quad (1)$$

where S_{TA} is the size of retention area (the size of the green circle in Fig. 1), which is predetermined by the information

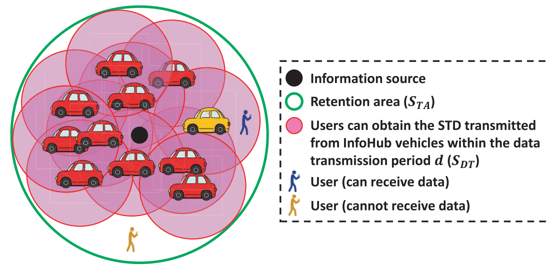

Fig. 1 STD retention system

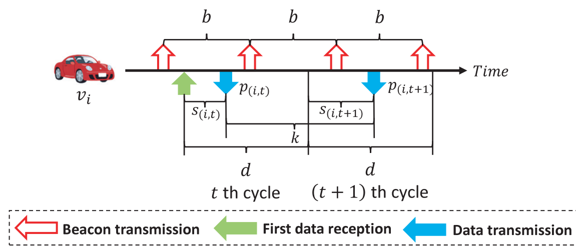

Fig. 2 Data transmission procedure

sender and S_{DT} is the size of the transmission range of STD transmitted from InfoHub vehicles within the transmission period d (total size of the pink area in Fig. 1). A high coverage rate means that users can automatically receive STD from anywhere within the retention area, so it is important to maintain a high coverage rate within the retention system.

3.3 Data Transmission Control

In this section, we will provide an outline of our previous work [2]. Firstly, we will describe the data transmission timing. Figure 2 shows the data transmission procedure. When each vehicle v_i receives data from other vehicles for the first time, it first checks the data transmission period d included in the received data. Then, the vehicle randomly determines the next transmission time $s_{(i,t)}$ within d in order to avoid data transmission collisions. Furthermore, $s_{(i,t)}$ is calculated at the beginning of each cycle.

Next, we will describe the data transmission probability. Each vehicle detects the number of neighboring vehicles $n_{(i,t)}$ from the number of received beacons. When the number of neighboring vehicles is more than four, its own vehicle's transmission range has the potential to be completely covered by that of all neighboring vehicles. For example, if the neighboring four vehicles are located to own vehicle's north, south, west, and east, they can completely cover the own vehicle's transmission range. Therefore, the data transmission probability $p_{(i,t)}$ is set based on the environment described below.

case1 $n_{(i,t-1)} \leq 3$:
Since the vehicle's transmission area cannot be completely covered by that of the neighboring vehicles, the vehicle has to set its transmission probability individually $p_{(i,t)}$ to 1.
case2 $n_{(i,t-1)} \geq 4$:
Since the potential for data collisions increases with the in-

crease in the number of data transmissions, it is necessary to limit the number of vehicles for maintaining high coverage rate, as much as possible. Therefore, the data transmission probability $p_{(i,t)}$ is determined based on the number of neighboring vehicles $n_{(i,t-1)}$ and the number of received data $l_{(i,t-1)}$ during the previous cycle.

3.4 Problems of the Previous Method

In previous method, since each vehicle randomly determines the transmission time $s_{(i,t)}$ within d, the transmission interval k between two consecutive transmissions reaches up to $2d$ at the maximum whereas the system requirement is that the user receives data within the transmission period d. At this time, if there is no vehicle transmitting data in the proximity (particularly in low vehicle density environments), the system requirements cannot be satisfied.

4. Proposed Method

In this section, we describe a method for facilitating efficient data retention in low vehicle density environments. We first define the minimum data transmission period and then introduce the data transmission period control.

In order to solve the problems related to the previous method, it is necessary to make the maximum transmission interval randomly determined smaller than d. Hence, the data transmission period must be set to half of d. This data transmission period d_{min} is then defined as the minimum data transmission period.

By setting the data transmission period to d_{min}, the data transmission interval can be prevented from exceeding d. However, the number of data transmissions increases twice. In order to suppress an increase in the number of data transmissions, our proposed method controls each vehicle's data transmission period based on the size of the area S in which the communications range does not overlap with the nearest vehicle (Fig. 3). This area cannot be covered by other vehicles in the retention area. Therefore, the larger this area, the more important the data transmission. Then, based on the results of our previous study, a case where the number of neighboring vehicles $n_{(i,t)}$ is three or less is defined as a low vehicle density environment, and the data transmission period is calculated according to the size of the non-overlapping area S using the following equation:

$$d_{low} = d - d_{min} * \frac{S}{S_{max}} \quad (2)$$

where d_{low} is the data transmission period set in a low vehicle density environment and S_{max} indicates the maximum size of the non-overlapping area when a blue vehicle in Fig. 4 communicates with a red vehicle in Fig. 4 located on the boundary of the communication range of the blue vehicle. The non-overlapping area S is calculated by the following equation:

$$S = \pi y^2 - 2\left\{y^2 \cos^{-1}\left(1 - \frac{h}{y}\right) - (y - h)\sqrt{h(2y - h)}\right\} \quad (3)$$

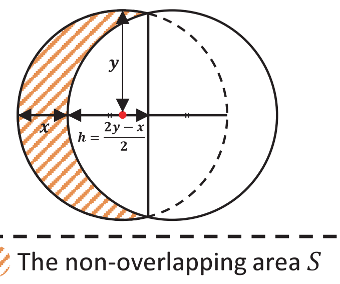

Fig. 3 Non-overlapping area

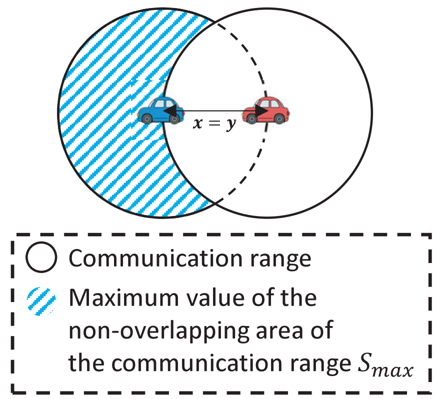

Fig. 4 Maximum value of the non-overlapping area

where y is the maximum communication distance, x is the distance between vehicles and h is the height of two identical arcs appearing at the overlap area.

As the distance between vehicles increases, that is, as the non-overlapping area increases, the data transmission period is controlled to approach the minimum data transmission period. Here, the calculation of the non-overlapping area of the communication range with multiple neighboring vehicles requires the location information of the neighboring vehicles. In this study, we assume that each vehicle does not exchange location information due to security issues. Therefore, we can't calculate the non-overlapping area of the communication range with multiple neighboring vehicles. However, since each vehicle can estimate the distance with a specific vehicle based on the received signal strength of the exchanged data, its own non-overlapping area can be calculated from the estimated distance with the vehicle. Note that in the proposed scheme, to avoid excess data transmissions, we need to maintain the transmission period d as long as possible. Therefore, we employ the nearest vehicle to calculate the non-overlapping area, which becomes the minimum size among the neighboring vehicles. After that, we control the transmission period by Eq. (2). In this study, for the simplicity, we used the free space propagation model.

5. Simulation

In this section, we evaluate the performance of our proposed method using simulations.

5.1 Simulation Model

We evaluated our proposed method using the Veins [11] simulation framework, which simultaneously implements both the IEEE 802.11p specification for wireless communications and the vehicular ad-hoc network (VANET) mobility model. Veins can combine the Objective Modular Network Testbed in C++ (OMNeT++) [9] network simulator with the Simulation of Urban MObility (SUMO) road traffic simulator [10].

To show the effectiveness of our proposed method, we used random topology in which vehicles with randomly generated starting and end points ran on a road grid with traffic lights at each intersection (Fig. 5). The intersection distance w was set to 50 m. We then created and evaluated 10 kinds of movement patterns. In this simulation, 20, 40 or 60 vehicles exist in the simulation area and we evaluated 100 seconds (the period from 600 to 700 s after the start of the simulation) in steady state, which is the state after the STD transmitted from the information source reaches the boundary of the retention area. Table 1 shows the simulation parameters. As the comparison method, we used a naive method, a previous method based on [2], and a periodic flooding method. The periodic flooding is a simple method for simulating the data retention system by exploiting a flooding method, which is a well-known data diffusion method in VANET and MANET. More specifically, in the periodic flooding method, the information source initially broadcasts the STD once every transmission period d, and then the vehicles receiving the STD forward it in order (i.e., flooding) until STD reaches the boundary of the retention area. In the naive method, all vehicles in the retention area hold the STD as in the proposed method. In addition, all vehicles always set the transmission probability $p_{(i,t)}$ to 1 and the data transmission period d to d_{min}. Therefore, in the naive method, since all vehicles transmit the STD, this

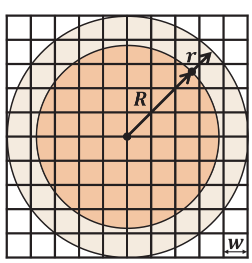

Fig. 5 Simulation topology

Table 1 Simulation parameters

Parameters	Values
Maximum communication distance y	300 m
Data transmission period d	5 s
Beacon interval b	5 s
Speed	40 km/h
Retention area radius R	750 m
Auxiliary area length r	250 m

method definitely achieves the highest coverage rate. However, when the vehicle density is high, data collisions are likely to occur, thereby causing the unnecessary consumption of wireless resource.

5.2 Performance Evaluation

Figure 6 shows the total number of data collisions. The error bar represents the maximum and minimum values of 10 simulation trials. From this result, it can be seen that since the periodic flooding method does not control the transmission timing, the number of data collisions is much higher than other methods. Therefore, the flooding method has lower communication quality than other methods.

Figure 7 shows the average coverage rate. From this result, it can be seen that the coverage rate of the periodic flooding method is much lower than that of other methods. Therefore, the periodic flooding method cannot realize the data retention. Also, the coverage rate of the previous method is lower than of the naive method, especially in the environment where the vehicle density is low, e.g. 20 vehicles. In contrast, our proposed method can achieve a coverage rate close to the naive method regardless of the vehicle density. In order to show the coverage rate in detail, Fig. 8 provides the ratio of the coverage rate of our previous and proposed methods to the naive method. Here, the coverage

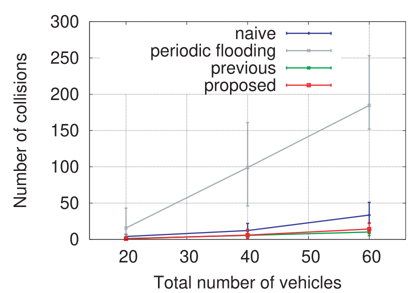

Fig. 6 Total number of collisions

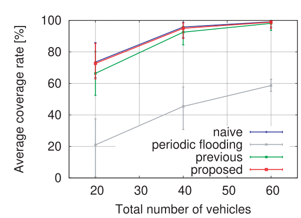

Fig. 7 Average coverage rate

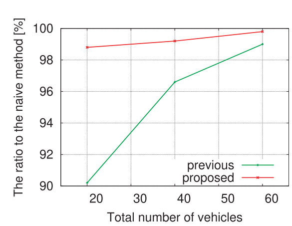

Fig. 8 The ratio to the naive method

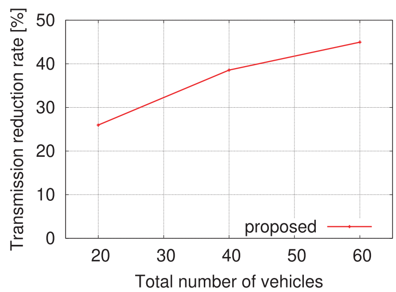

Fig. 9 Transmission reduction rate

rate of the naive method is presented as 100. In our previous method, the ratio decreases drastically as the vehicle density decrease. However, in our proposed method, the ratio is more than approximately 99% at any vehicle density. Thus, we can conclude that our proposed method can achieve data retention close to that of the naive method, regardless of vehicle density.

Figure 9 shows the reduction rate of the number of data transmissions compared with that of the naive method. It can be seen that our proposed method can reduce the number of data transmissions by approximately 25% even in the vehicle density is low. From these results, we can conclude that our proposed method can achieve the coverage rate of approximately 99% while reducing the number of data transmissions by approximately 25% even in the vehicle density is low, compare to the naive method.

6. Conclusions

In this paper, we proposed a system that facilitates the retention of STD in a specific area by using an ad-hoc network constructed solely by InfoHub vehicles. Additionally, our proposed STD retention system improves coverage rates in low vehicle density environments by controlling data transmission periods based on the size of the area in which the communications range of one vehicle does not overlap with the nearest vehicle. Through simulations, we clarified that the proposed method can achieve effective data retention even when the vehicle density is low. In our future work, as part of efforts for further coverage rate improvements, we will verify a novel STD retention system that cooperates with Mobile Edge Computing (MEC).

Acknowledgments

This work supported in part by JSPS KAKENHI Grant Number 18H03234 and 20K11792, NICT Grant Number 19304, and NSF award number 1818884 (JUNO2), 1827923 (COSMOS).

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