Beacon-less Autonomous Transmission Control Method for Spatio-Temporal Data Retention

Ichiro Goto, Daiki Nobayashi, Kazuya Tsukamoto, Takeshi Ikenaga, Myung Lee

Abstract With the development and spread of Internet of Things (IoT) technology, the number of devices connected to the Internet is increasing, and various kinds of data are now being generated from IoT devices. Some data generated from IoT devices depends on geographical location. We refer to such data as spatio-temporal data (STD). The "local production and consumption" of STD is effective for applications based on location. Therefore, we have proposed a STD retention system using a vehicular ad hoc networks. In this system, each vehicle dynamically adjusts the data transmission probability according to the density of neighboring vehicles to achieve effective data retention. However, since the overhead of beacon messages required for estimation of the neighboring vehicle density becomes a critical problem with the increase in the number of vehicles, thereby preventing the effective data retention. In this paper, we propose a new data transmission control method to realize effective and reliable STD retention without beacon. Simulation results showed that our proposed scheme can achieve effective data retention.

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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 IoT devices is growing year by year and is expected to grow to approximately 28 billion by 2022 [1]. Therefore, various kinds of data are now being generated from IoT devices and are mostly collected, analyzed and distributed by Internet cloud servers.

Here, when we pay attention to data content generated from IoT devices, some data content such as traffic information, weather information and disaster information are highly dependent on location and time. We define such data content as "spatio-temporal data (STD)." STD can be effectively utilized by distributing it directly to the user from generation place of it. For example, when a traffic accident occurs, the driver distributes the information about traffic accident to other neighboring drivers directly. As a result, these drivers can passively acquire the information about traffic accident without any kind of active actions, so that drivers can take an action to avoid a route where a traffic jam occurs. In other words, we suppose that "local production and consumption of data" brings us effective utilization of STD.

Therefore, we have proposed a novel Geo-Centric Information Platform (GCIP) for collecting, analyzing, and delivering STD based on physical space [2]. As a fundamental element of GCIP, we have also proposed a STD retention system usig vehicles equipped with storage modules, computer resources, and short-range wireless communication equipment [3][4][5]. In this system, vehicles capable of wireless communication are defined as regional information hub (InfoHub), and the purpose of this system is to retain STD within a target area.

However, in the data retention method using a vehicular ad hoc networks, since all vehicles use the same radio band, radio interference occur frequently when the number of vehicles increases. Therefore, in the previous study, in order to solve this problem, we proposed a transmission control method according to the data transmission situation of neighboring vehicles [3][4][5]. Those methods control the transmission probability based on the density of neighboring vehicles. However, since the beacon messages periodically transmitted from each vehicles are used for estimation of the vehicle density, the overhead of beacon transmission can become a crucial problem especially in a high vehicle density environment, thereby causing frequent radio interference.

In this paper, we propose a new beacon-less transmission control method. In the proposed method, we first introduce transmission zones in which vehicles can transmit data for data retention. Next, we introduce time division mechanism of the transmission timing among neighboring transmission zones to avoid radio interference. Finally, we control the transmission based on the signal strength of packet received from neighboring vehicles in order to distribute the data to the entire retention area with minimum data transmission. We evaluate the performance of the proposed method by simulation and verify its effectiveness.

The rest of this paper is organized as follows. In Section 2, we briefly review studies related to data retention, while we outline our previous STD retention system and discuss the problems to be addressed in Section 3. In Section 4, we describe our new transmission control method for STD retention, while simulation models and evaluation results are provided in Section 5. Finally, we give our conclusions in Section 6.

2 Related Works

Maihofer et al. proposed an abiding geocast, which distributes and retains data to all vehicles within the geocast target area for a certain period of time [6]. Maihofer et al. also proposed three methods for distributing and retaining data to vehicles in the target area. The first is a server approach where a particular server retains the data and periodically distributes it based on the geocast routing protocol. In this method, not only the specific server distributes the data but also the location information of all vehicles in the target area needs to be exchanged in order to distribute the data, so that the load to the specific server is increased. The second is an election approach in which selected vehicles in the target area retain data and distribute it periodically. These two approaches increase the processing load for a particular server and vehicle, which result in more frequent failures. In addition, when these devices fail, data cannot be distributed.

The third is a neighboring approach in which each vehicles within the target area hold data and vehicle location information, and deliver data when they sense vehicles entering the target area. This approach requires no infrastructure because it is a vehicle-only system. Therefore, the range of practical use is wide, and many studies have been conducted. Rizzo et al. proposed a method to exchange information between vehicles based on the assumption that the infrastructure could not be used due to a disaster [7]. Leontiadis et al. proposed a method in which a vehicle exchanges navigation information with neighboring vehicles and distributes data to a vehicle heading to a target area [8]. In the Floating Content [9] and Locus [10], vehicles have a data list and exchange the list with neighboring vehicles. When the vehicle does not retain the data, the vehicle makes a transmission request, and the vehicle retaining the data transmits the data. At this time, the vehicle determines whether to transmit the data based on the data transmission probability set according to the distance from the center of the target area. Therefore, the further the vehicle is from the center, the lower the data acquisition probability is. On the other hand, when many vehicles are located near the center, channel competition occurs because the transmission probability of all vehicles is high, and communication quality deteriorates. Furthermore, since the user has to send a query to acquire these data, there is an overhead in acquiring the data, which is inefficient for acquiring real-time information (For example, traffic information). Therefore, in this study, we propose a new network infrastructure that retains STD at the generation place and effectively distributes it to users in order to promote local production and consumption of data.

3 STD Retention System

In this section, we describe the assumptions, requirements, and outline of the retention system [3], and then discuss the related problems.

3.1 Assumption

InfoHub vehicles have a wireless interface that meets the IEEE 802.11p specification and obtain location information using a Global Positioning System (GPS) receiver. STD includes not only data for an application but also transmission control information such as a center coordinates, a radius R of the retention area, a length r of an auxiliary area, and a data transmission interval d. Vehicles in the retention area transmit data once every data transmission cycle (interval d). In addition, all vehicles are equipped with the same antenna and have the same transmission power.

3.2 System Requirements

To achieve data retention, the entire retention area must be covered by sum of the communication range of InfoHub vehicles. Further, in order to realize the quick data distribution to users, the data must be transmitted from InfoHub vehicles to the entire retention area at regular intervals so that users can receive the data in a short time (at least once every transmission interval d). In this paper, we defined coverage rate as an indicator of the data retention performance in a certain period. The coverage rate formula is as follows:

$$Coverage\ Rate = \frac{S_{DT}}{S_{TA}} \tag{1}$$

where S_{TA} is the size of retention area and S_{DT} is the size of the total area where a user can obtain the data transmitted from InfoHub vehicles within the data transmission interval. Figure 1 shows an example of the coverage. The black dot indicates vehicles, and the pink circle indicates the communication range. As shown in the Fig. 1(a), a high coverage rate means that users can passively acquire data anywhere within the retention area. On the other hand, as shown in the Fig. 1(b), a low coverage rate means that users are highly likely to be unable to passively acquire data in the retention area. Therefore, maintaining a high coverage rate is important for the data retention system. In addition, in an environment with high vehicle density, since multiple vehicles frequently transmit data simultaneously, a lot of radio interference occur, thereby degrading the data retention performance. Therefore, the requirement of this system is to maintain a high coverage rate, while limiting the number of data transmissions as much as possible.

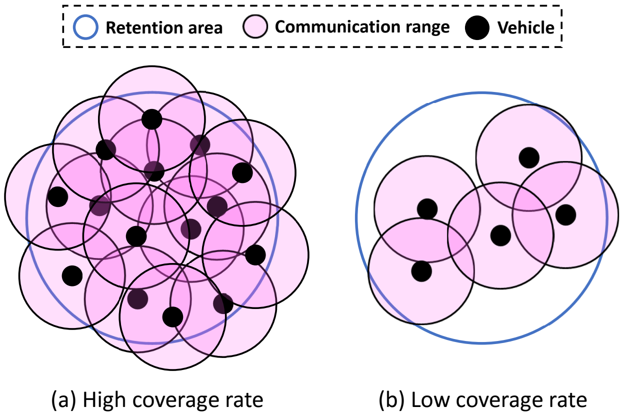

Fig. 1 Coverage rate

3.3 Previous Method

Previous method controls the data transmission probability using simple information, such as the number of neighboring vehicles and the data reception number. Each vehicle periodically transmits a beacon in order to estimate the number of neighboring vehicles based on the number of beacons received from the neighboring vehicles, and sets a data transmission probability based on the number of beacons and data received at each data transmission interval d. As a result, the previous method achieved a high coverage rate while reducing the number of data transmissions.

3.4 Problems of the Previous Method

In the previous method, since each vehicle estimates the number of neighboring vehicles from the number of received beacons, all vehicles in the retention area must transmit beacons. Therefore, the number of beacon transmissions inherently increases in proportion to the increase in the number of vehicles. That is, although the previous method can reduce the number of data transmissions effectively even in the high dense environment, the effects of overhead of beacon messages and collisions between data and beacons are not taken into consideration at all. Therefore, in order to realize effective data retention, it is necessary to beacon-less data transmission control.

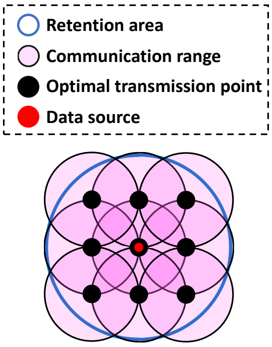

Fig. 2 Optimal transmission point

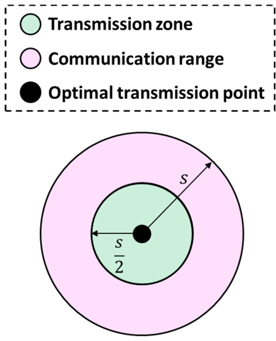

Fig. 3 Transmission zone

4 Proposed Method

In this section, we propose a method to realize effective data retention without beacon transmissions. First, we introduce transmission zones that vehicles can transmit data within the retention area. Next, in order to suppress the radio interference between neighboring transmission zones, we assign one transmission interval for each transmission zone within one data transmission cycle. Finally, the vehicle controls the transmission based on its own location and the signal strength of packet received from neighboring vehicles.

4.1 Introduction of Transmission Zones

In this study, first, we defined the minimum required transmission position (hereinafter called ”optimal transmission point”) that covers the entire retention area based on the communication range of one vehicle. Since not only the origin point of STD but also the range of communication coverage are predetermined, we can know the optimal transmission points in advance. Therefore, as shown in Fig. 2, we set the optimal transmission points determined based on these information. If only vehicles located at the optimal transmission points transmit data, the number of data transmissions can be minimized. However, in the real environment, since vehicles freely move with high mobility, the reliable transmission from the optimal point is impossible. Therefore, we introduce the transmission zone whose center is the optimal transmission point as shown in the Fig. 3, and only vehicles within the transmission zone transmit data, aiming to maintain a high coverage rate.

4.2 Decision of Transmission Timing in the Transmission Zone

We set the transmission timing according to the following procedure so that the vehicle closer to the optimum transmission point transmits data preferentially within the transmission zone. Initially, we assume that all vehicles synchronize time, and data transmission cycle using GPS. First, each vehicle acquires its own current position at every data transmission cycle, and confirms whether its own position is located within the transmission zone. When the vehicle is in the transmission zone, the vehicle calculates the distance to the nearest optimal transmission point and sets the transmission timing by following the formula.

$$Next\ Transmission\ Timing = \frac{l}{s/2} * d + Current\ Time \tag{2}$$

where l is the distance from the optimal transmission point, s is the radius of communication range and d is the transmission interval. In this formula, the transmission timing is set earlier as the vehicle is closer to the optimum transmission point. Thus, the data can be transmitted from the vehicle close to the optimal transmission point.

On the other hand, when the vehicle is outside the transmission zone, the vehicle does not set the transmission timing (not send data packet) during this data transmission cycle.

4.3 Time Division Scheduling among Transmission Zones

In order to determine the transmission timing according to the distance from the optimum transmission point, since all the vehicles must synchronize the data transmission cycles, vehicles located in the two neighboring transmission zones whose distance to the optimal transmission point is the same, transmit data simultaneously, causing radio interference. Therefore, we introduce a method to avoid radio interference between neighboring transmission zones. To avoid radio interference, we treat the neighboring 9 transmission zones as one group and one transmission interval is allocated to each of transmission zone within one data transmission cycle, as shown in Fig. 4. Then, the vehicles in transmission zone set the transmission timing described in Section 4.2 within the transmission interval assigned to each transmission zone. Thus, since the transmission timings of the neighboring transmission zones are different from each other, radio interference can be prevented.

4.4 Transmission Control Based on the Received Signal Strength

In the previous section, each vehicle decided the transmission timing based on the distance from optimal transmission point. Next, each vehicle determines whether to

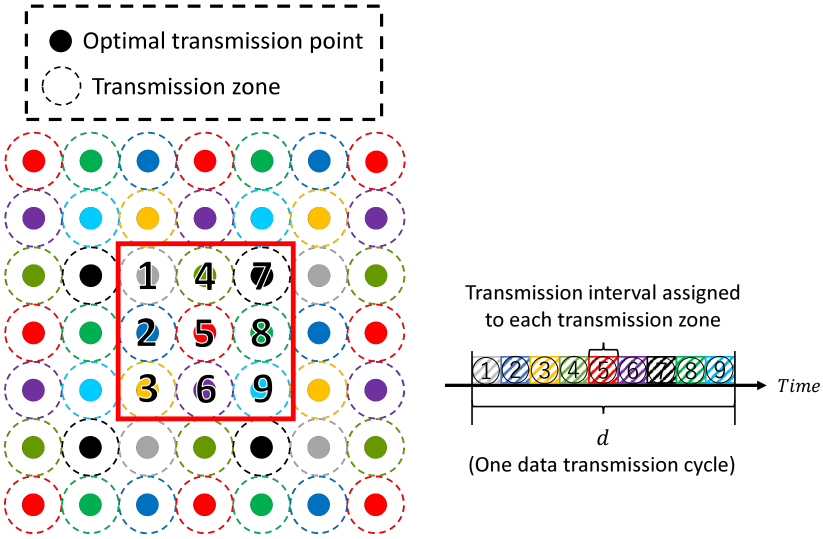

Fig. 4 Grouping of transmission zones

transmit data based on the surrounding transmission situation. The ideal environment for this system is to transmit data at the optimal transmission point in free space. Thus, by comparing the received signal strength in this ideal environment with the actual received signal strength, we can determine whether transmission is required at that location. When the received signal strength of the data is higher than the ideal received signal strength, the vehicle does not need to transmit the data because the space around the vehicle has a sufficient signal strength. On the other hand, when the received signal strength of the data is lower than the ideal received signal strength, since the propagation environment around the vehicle is poor and areas where radio waves do not reach occur, the vehicle needs to transmit data. Therefore, the vehicle in the transmission zone controls transmission according to the following procedure.

1. When the vehicle receives the data, the vehicle acquires the current position information.
2. The vehicle confirms whether the received data is data transmitted from the same transmission zone as itself.
   a. When the transmission zones are the same, the vehicle calculates a distance to the optimal transmission point, and calculates an ideal received signal strength at the current position by using the Friis transmission equation.

$$P_r = G_t G_r p_t \left(\frac{\lambda}{4\pi r}\right)^2 \tag{3}$$

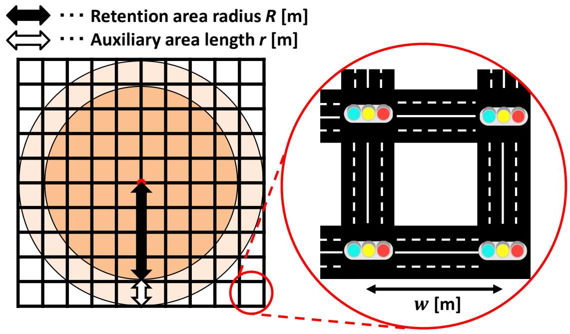

Fig. 5 Simulation model

where P_r is the received power, G_t is the transmission gain, G_r is the receive gain, P_t is the transmission power, λ is the wavelength and r is the distance from transmission point. Next, the vehicle compares the calculated value with the measured value. When the measured value is large, the vehicle does not transmit the data in the current data transmission cycle and waits until the next data transmission cycle.

b. When the transmission zones are different, the vehicle waits until the transmission timing.

5 Simulation Results

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

5.1 Simulation Model

We evaluated our proposed method using the Veins [14] simulation framework, which implements both the IEEE 802.11p specification and mobility model for the vehicular ad-hoc networks (VANETs). The veins can combine the Objective Modular Network Testbed in C++ (OMNeT++) [12] network simulator with the Simulation of Urban MObility (SUMO) road traffic simulator [13]. To show the effectiveness of our proposed method, we used random topology (Fig. 5) that vehicles with randomly generated starting and ending points drive on a road. A traffic signal was installed at the intersection. The distance between intersections w was 50 m. In our simulations, we set each parameter to evaluate our proposed method based on the previous method [3]. The retention area radius R was set to 750 m, the auxiliary area length r was set to 250 m, the communication range of the vehicle was set to 300 m, the speed was set to 40 km/h, and the transmission interval d was set to 5 s. We created 10 mobility models for vehicles with randomly generated starting and ending points, and evaluated them by changing the number of vehicles in each model from 250 to 1000. As comparison methods, we used a naive method that a vehicle always sends data at least once during the transmission interval d, the previous method [3], the proposed method without the time division scheduling (TDS) of Section 4.3, and the proposed method with the scheduling. In the previous method, the beacon transmission interval was set to 5 s, the moving average coefficient α was set to 0.5, and the target value of the number of received data β was set to 4 in addition to the above parameter setting.

5.2 Performance Evaluation

First, we evaluate the coverage rate. Figure 6 shows the coverage rate of the four comparison methods. From this graph, the proposed method achieve a coverage rate approximately 100% as the previous method regardless of the number of vehicles. This result shows that the proposed method can distribute STD to the entire retention area without beacon transmissions regardless of the number of vehicles.

Next, we evaluate the number of retained STD transmissions as shown in Fig. 7. From this graph, the proposed method can suppress the number of retained STD transmissions to around 100, which is the same as the previous method, even in an environment with high vehicle density. This result shows that the proposed method can realize the same reduction of the number of data transmission as the previous method by controlling the transmission according to the signal strength of the received data. On the other hand, Fig. 8 shows the total number of data transmissions to the retention area. This means the number of transmissions of all data, including the beacons, not just the retained STD. From this result, since all vehicles in the previous method transmit beacons, the total number of data transmissions to the retention area is larger than that of the naive method. As a result, the previous method is difficult to achieve effective data retention because the frequency of radio interference may increase. On the other hand, since the proposed method does not transmit beacons, the total number of data transmissions to the retention area is significantly smaller than other methods. These results indicate that the proposed method can achieve data retention with minimum data transmission.

Finally, we evaluate the radio interference. Figure 9 shows the number of occurrence of radio interference. From this graph, the performance of the proposed method without TDS is equivalent to the previous method. Furthermore, the proposed method with TDS can suppressed the total number of occurrence of radio interference to approximately one tenth of the previous method. This results shows that the proposed method hardly occur radio interference by time division scheduling even in an environment with high vehicle density. These results show that the proposed method can significantly reduce the number of data transmissions and ra-

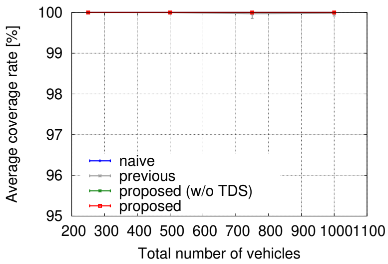

Fig. 6 Coverage rate

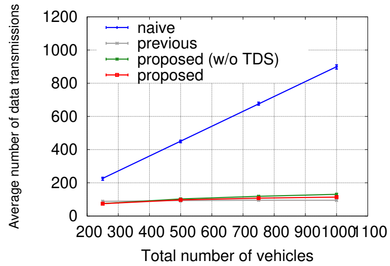

Fig. 7 The number of retained STD transmissions

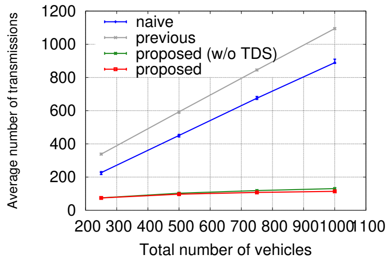

Fig. 8 The total number of data transmissions

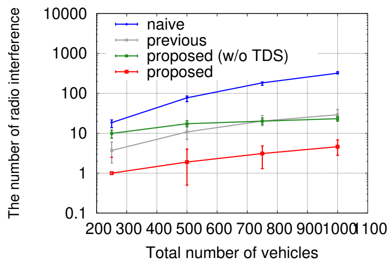

Fig. 9 The number of occurrence of radio interference

dio interference without beacon transmissions, while achieving a coverage rate of approximately 100% regardless of the number of vehicles.

6 Conclusions

In this paper, we proposed a STD retention system that enables passive data reception in a specific area using a VANET composed of InfoHub vehicles. Additionally, we also proposed a transmission control method to realize effective data retention without beacon transmissions. The proposed method controls data transmission based on the transmission position and the received signal strength of data. Simulation evaluation revealed that our proposed method can significantly reduce the number of data transmissions and radio interference while achieving a coverage rate of approximately 100% regardless of the number of vehicles. In our future work, we will evaluate using a vehicle traffic model that simulates a real environment such as LuST[11].

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