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***Abstract*—With the development of IoT technology, various kinds of data are generated by IoT devices. Some of this data contains information on geographical location and time. We refer to such data as spatio-temporal data (STD). Since the "local production and consumption" of STD is effective for location-dependent applications, we have proposed an STD retention system that utilizes vehicles as data sources. STD sources ranges from simple sensory data to large video data. However, since previous methods assumed to retain an STD consisting of only one packet, retention of large STD sources may suffer from frequent packet collisions due to the increase in the number of packet transmissions. In this paper, we propose a data completeness-aware transmission control mechanism for large STD retention. Our simulation results showed that the proposed scheme reduces channel collision by suppressing the forwarding of incomplete data, and achieved a nearly 100% coverage rate.**

***Index Terms*—Vehicular networks, Local Production and Consumption of Data, Spatio-Temporal Data Retention**

I. Introduction

With the development of Internet of Things (IoT) technologies, IoT devices generate various types of data. For most IoT applications, the data is collected on a cloud server on the Internet, analyzed for each application on the cloud server, and then provided to users as a service. According to Cisco Systems, there will be 29.3 billion network devices in 2023, up from 18.4 billion in 2018 [1]. However, operational costs increase because large-scale storage and high-performance CPUs are required for data accumulation and analysis. On the other hand, some data, such as traffic and weather information, is dependent on the location and time at which the data was generated. We define such data as spatio-temporal data (STD). STD can be used most effectively where and when it is generated. That is, the "local production and local consumption of data" paradigm is especially effective for STDs. However, with current IoT services, as mentioned above, data is aggregated once in the cloud, so it is not possible to take advantage of the features of STD that can be used in a local area. Therefore, a novel network infrastructure is needed to utilize STD directly at the location where it is generated. In recent years, horizontal information spread using V2V communication utilizing vehicular ad hoc networks (VANET) has attracted attention because vehicles will be expected to have a large data storage capacity, high-performance computing resources, short-range wireless communication devices, and high mobility [2] [3].

In prior research, we proposed an STD retention system utilizing VANET as a means to distribute and retain STD directly at a particular location [4] [5]. In the proposed scheme, we defined each vehicle as a regional information hub (InfoHub), distributing and accumulating STD. Such a system allows local production and consumption of data by constraining the STD to a specific area.

STD sources range in size from sensory data to large video traffic. By retaining those STD sources, the STD retention system promotes local information distribution to a greater extent and enhances the utilization of STD. However, previous studies related to STD retention systems assumed that the STD consisting of only one packet is retained regardless of whether the STD is fully contained in one packet or not. Therefore, retention of large STD may suffer from frequent collisions of wireless communication channel due to the increase in the number of packet transmissions. As a result, the accessibility of the STD to users of the system may be reduced wireless resources may be consumed unnecessarily.

In this paper, we propose a transmission method that considers the data completeness of large STD. In the proposed method, InfoHub vehicles (hereafter, referred to simply as nodes) do not re-broadcast the STD until all packets constituting the STD are successfully received, thereby ensuring data completeness. By suppressing the transmission of incomplete STD, the proposed method reduces packet collisions and waste of wireless resources. Through simulation-based evaluations, we will demonstrate that our proposed method can retain large STD efficiently.

In related work, Floating Content [6], Locus [7], and Hovering Information [8] have been proposed to maintain data at a specific place using vehicles. In the Floating Content [6] and Locus [7] system, a user must send a query to the vehicle group in order to acquire desired data. Furthermore, data for the query must be searched from moving vehicles and the results sent back to the user using moving vehicles. In [8], it is necessary for a vehicle to transmit continuously its own direction of movement, position, and storage capacity, etc., to nearby vehicles because each vehicle judges the next hop by those information. Therefore, a high overhead for data distribution is a problem with these methods. On the other hand, the STD retention system enables passive data reception by users by spreading, maintaining, and distributing data through efficient broadcasting. [9] [10] investigated the issue of large-capacity data transmission using VANET. [9] proposed the model which shows the characteristic of the maximum amount of information stored in the area for given system parameters in the Floating Content method. In [10], Zhu et al. proposed a method in which multiple vehicles collaboratively download large-capacity data from Road Side Unit (RSU) using network coding technology. However, this method assumes that there are multiple vehicles near the RSU interested in the common large-capacity data and driving in the same direction. Therefore, when there are no RSU nearby or few vehicles in the area, the vehicle cannot acquire large-capacity data. Moreover, the scheme does not consider the data distribution from the vehicle to the user at which the STD retention system aims.

The remainder of this paper is organized as follows. In Section II, we outline our prior approach. In Section III, we describe our proposed transmission method based on data completeness. Section IV provides the simulation model, simulation results, and discussion. Finally, we provide conclusions in Section V.

II. STD Retention System

In this section, we describe the assumptions and requirements for the STD retention system. Then, our previous research [5] is outlined, and its limitations are described.

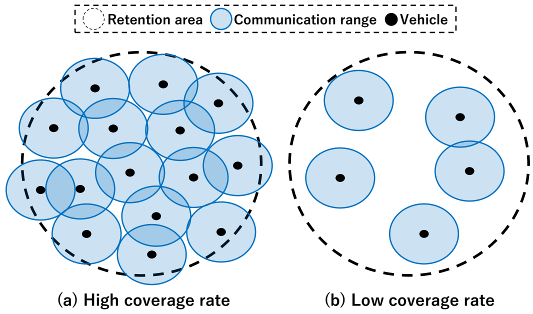

Fig. 1. Coverage rate.

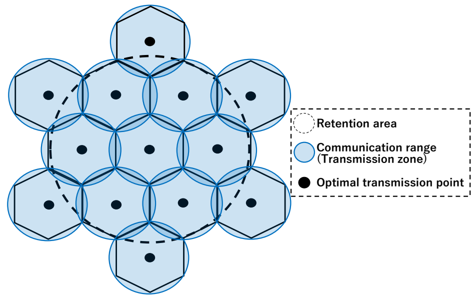

Fig. 2. Regular hexagon type optimal transmission point.

A. Assumptions

Nodes are equipped with wireless modules based on IEEE802.11p. Each node can specify and obtain location information using a Global Positioning System(GPS) receiver. In addition, all nodes are equipped with the same antenna and have the same transmission power. STD packets include not only data for an application but also parameters for data retention, such as center coordinates, a radius of retention, R, and a data transmission interval, d. The sender of the STD sets these parameters, and the retention area with radius R is formed around the sender. Within the retention area, users of the system can receive STD every d.

B. System Requirements

The goal of the STD retention system is to enable all users in the retention area to acquire STD quickly but passively. Therefore, the whole retention ares is to be within the communication range of the nodes. Furthermore, to deliver STD to users quickly, nodes in the whole retention area must transmit the STD within every data transmission interval, d. We define the coverage rate as a performance measure for the STD retention performance in a certain period:

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

where S_{TA} is the size of the retention area and S_{DT} indicates the size of the total area where a user can obtain STD transmitted from nodes within a data transmission interval,

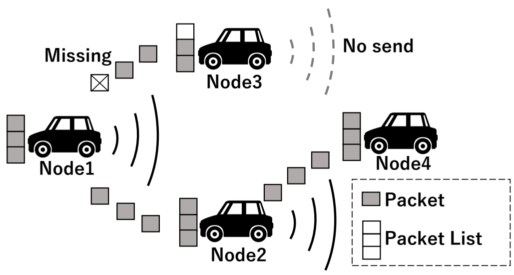

Fig. 3. Completeness-aware transmission control.

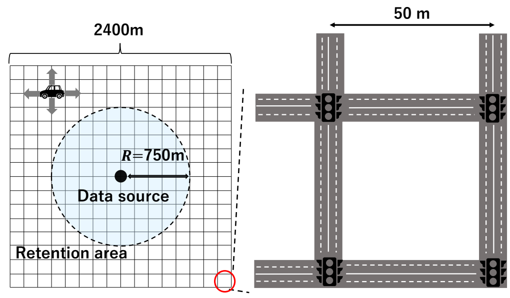

Fig. 4. Simulation topology.

TABLE I
SIMULATION PARAMETER.

Parameter	Setting
Number of nodes	200units
Node communication range	300m
Node speed	40km/h
Cycle of traffic signal	90s
Retention area radius R	750m
Packet size	1500Bytes
Data transmission interval	5s
STD size	10,20,30,40,50packets
Simulation time	120s

d. Figure 1 shows an example of coverage. The black dots indicates nodes and the blue circles for the communication range. As shown in Fig. 1(a), a high coverage rate means that users can passively acquire STD anywhere within the retention area. On the other hand, as shown in Fig. 1(b), a low coverage rate means a low probability of acquiring STD in the retention area. Therefore, maintaining a high coverage rate becomes important. However, in an environment with a high nodal density, a large amount of radio interference could occur since multiple nodes transmit STD simultaneously, thereby degrading the STD retention performance. Hence, a desirable system requires maintaining a high coverage rate while also minimizing data transmission as much as possible.

C. Previous Method

This section describes the transmission controls proposed by the previous method [5]. First, the previous method defined the minimum number of required transmission positions (hereafter referred to as the "optimal transmission point") to cover the whole retention area based on the communication range of nodes. Figure 2 illustrates the optimal transmission point. If each node is located at its optimal transmission point, the number of times the data is transmitted is minimized because the total area of individual nodes' communication range can cover the retention area. However, the node does not necessarily lie at the optimal point because the node is moving. Therefore, the nodes around each point control the transmission of data based on the communication status of the surrounding nodes, which in turn reduces the number of times the data is transmitted while maintaining a high coverage rate. In addition, the previous method achieves effective retention by controlling the data transmission for each node in the transmission zone formed around the optimal transmission point with a communication range as a radius.

Second, in this method, the coverage rate of the transmission zone increases as the data is transmitted from the point close to the optimal transmission point. Therefore, the previous method sets the transmission timing of each node within the transmission zone using the following equation:

$$NextTransmissionTiming = \frac{l}{s/2} * d + CurrentTime \tag{2}$$

where l is the distance from the optimal transmission point, s is the radius of the communication range, and d is the transmission interval.

Third, transmission control based on the received signal strength, was proposed to avoid radio interference in a zone. When each node receives data from a node in the same transmission zone, the receiving node determines whether it is necessary to transmit by confirming the received signal strength. The node calculates the distance to the optimal transmission point and calculates the received signal strength in an ideal wireless communication environment at the current position. Next, the node compares the calculated received strength with the strength of the signal that was actually received. When the actual value is higher than the calculated value, the node does not transmit data in the current transmission cycle because the space around the node has sufficient signal strength. On the other hand, if it is lower than the calculated value, the node needs to transmit STD since the propagation environment around the node is poor. Therefore, the node itself transmits and covers the surroundings. Through this control mechanism, the transmission zone can be covered with the minimum number of transmissions, and radio interference is suppressed.

D. Problems of the Previous Method

The previous method [5] focused on retaining STD consisting of only one packet. On the other hand, it is assumed that the diversity of STD sources will increase, e.g., in image or video format, with the development of IoT technology. Therefore, the STD retention system also needs to correspond to such large STD, constructed with multiple packets. However, retention of large STD causes radio interference

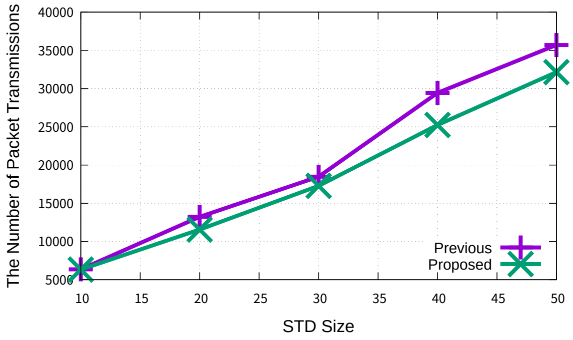

Fig. 5. The number of packet transmissions.

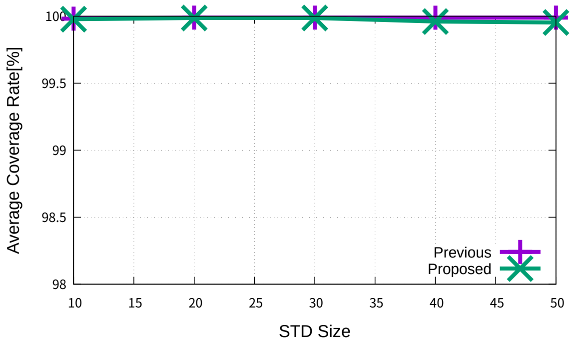

Fig. 6. Coverage rate.

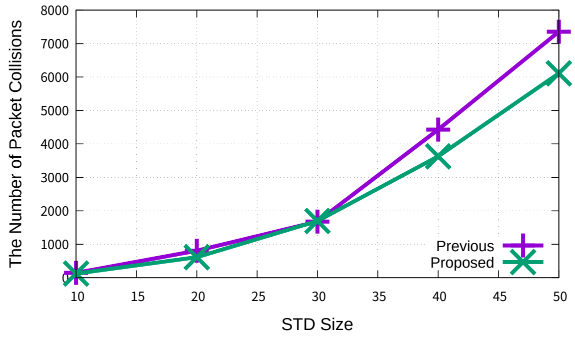

Fig. 7. The number of packet collisions.

due to increased frequency of transmission. Therefore, some nodes may receive incomplete STD in which a part of packets constituting the STD is missing. In the previous method, since such nodes also broadcast, the radio environment deteriorates more and more. In this paper, we propose a transmission control to broadcast only STD with verified completeness for large STD retention.

III. PROPOSED METHOD

In this section, we describe the proposed transmission control mechanism for large STD retention. As in the previous method, the STD sender sets parameters such as the retention area radius, R, and the retention area is formed around the sender. Figure 2 shows the optimal transmission point and transmission zone arrangement in the proposed method. Using this arrangement, the proposed method operates the transmission control mechanism based on the previous method.

When nodes retain a large STD constructed from multiple packets in the previous method [5], some nodes may lose some of the forwarding packets due to channel interference. If a node forwards an incomplete STD, the node that receives the STD cannot use it. Therefore, forwarding of incomplete STD leads to the waste of wireless resources and increases redundant packet transmissions in the whole area.

In this study, we propose a data completeness-aware transmission control for large STD retention. In the proposed method, each node prevents redundant STD transmissions based on the completeness of the received STD. First, each packet of a large STD is assumed to contain a sequence number and the number of packets that construct the STD. Next, each node maintains a list of receiving statuses for each packet of the large STD and updates the list whenever receiving a new packet. When the time comes for a node to transmit data, based on the previous method [5], the node controls data transmission according to the state of receiving packets. If the node has all packets for the large STD, it forwards all of them by broadcast.

Figure 3 shows an example of forwarding a large STD constructed from three packets. Node1 forwards three packets, which are sequentially broadcast, and node2 and node3 receive the packets. In this example, node2 receive all three packets, whereas node3 misses the third packet. In such a case, node2 re-broadcasts the three packets at the time of the next transmission by following the previous work. On the other hand, node3 drops the three packets since node3 cannot confirm the completeness of the three packets. As a result, our proposed method decreases channel collision of wireless communication and improves the utilization efficiency of wireless bandwidth by suppressing transmissions of unnecessary STD.

IV. PERFORMANCE EVALUATION

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

A. Simulation Models

We evaluate our proposed method using the Veins [11] simulation framework, which implements both the IEEE 802.11p specification and the mobility model for the VANET. 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]. As shown in Fig. 4, we used a grid-type road model, on which each node runs randomly. The other main simulation parameters are shown in Table I. STD size varies from 10 packets to 50 packets to investigate the impact of large STD retention. Nodes distribute these packets sent from the data source in the retention area by re-broadcast. We compare the performance of the proposed method with the previous method explained above

[5] when the STD size varies. Furthermore, we introduce the extended coverage rate as the performance metric.

$$Extended\,Coverage\,Rate = \frac{S_{CDT}}{S_{TA}} \tag{3}$$

where S_{CDT} indicates the area where all packets constructing the STD have arrived within the data transmission interval d.

B. Simulation Results

First, Figure 5 shows the number of transmission packets. The proposed method reduced the number of packet transmissions compared to the previous method by not transmitting incomplete STD. The packet reduction ratio increases as the STD size increases and shows about 20% reduction when the STD size is 50.

Figure 6 shows the extended coverage rate for the proposed method and the previous method. The extended coverage rate for the proposed method was almost 100%, as was the case for the previous method. Considering the results in Fig. 5, it is clear that the proposed method can maintain a high extended coverage rate while reducing the number of packet transmissions.

Figure 7 shows the number of packet collisions in the wireless channel. The proposed method experiences less packet collision compared to the previous method as expected from the result in Fig. 5. The reduction ratio increases along with the STD size. The reduction rate is approximately 10%-20% based on the increase in the number of packets constructing the STD. These results show that the proposed method can reduce packet collisions by suppressing the forwarding of incomplete STD.

V. CONCLUSION

In this paper, we proposed a data completeness-aware transmission control mechanism for large STD retention. Our simulation results showed that the proposed method can reduce packet collisions by suppressing the forwarding of incomplete STD, and achieved approximately a 100% coverage rate. In future work, we intend to evaluate the retention of large STD using more practical topology scenarios.

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