Roadside Unit Allocation for Fog-based Information Sharing in Vehicular Networks

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ABSTRACT

As more intelligent vehicles will ply the roads in the near future, a rapid increase of sensed environment data is anticipated. Information based on these acquired data needs to be extracted and shared in the most efficient way. To realize this, roadside units (RSUs) acting as hotspots and fog computing nodes should work together with vehicles in vehicular networks and intelligent transportation systems. In this paper, we consider a set of intersections in the city of Beijing as potential locations for strategically allocating fog computing hotspots to maximize the information shared among vehicles and fog nodes. Using empirical findings from mobility traces such as vehicular density, total daily number of transmissions, transmitted data size, and space mean speed, we propose the Information Sharing via Roadside unit Allocation (ISRA) strategy to determine the optimal locations for these fog computing hotspots. Simulation results show that for a given deployment limit, ISRA, when compared to three other conventional deployment schemes, is able to share on average 6%, 10% and 47% more road information with fewer packet transmissions (energy efficiency of 83%) in the vehicular network. In addition, ISRA is able to balance the information load among adjacent RSU fog nodes for better resource management.

KEYWORDS

Vehicular Networks, Roadside Unit, Fog Computing Applications, Empirical GPS Traces

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1 INTRODUCTION

Vehicular networks are characterized with high degree of vehicular mobility and dynamic network availability, connectivity, and topology [1]. Because of these, huge and continuous data sharing, and complicated and time-critical computations for decision-making among vehicles are impractical. A reasonable approach for information sharing in vehicular networks should have the roadside infrastructure or roadside units (RSUs) integrated with the fog computing paradigm [2]. These RSUs acting as fog computing nodes can enable efficient data exchange, processing, storage, and dissemination of important traffic and environmental information among vehicles and the road infrastructure [3]. Once a sufficient amount of data has been collected, RSUs, having a more powerful computational resources and more comprehensive knowledge regarding the vicinity over vehicles, can analyze and potentially control the vehicular traffic [4]. RSUs as fog nodes can eventually reduce traffic latency and improve the quality of service between the infrastructure and vehicles. The fog computing paradigm, once integrated into the vehicular networks, can support a variety of possible applications.

There have been already several application scenarios employing RSUs as fog nodes [5–7]. The most common use-case scenario is a traffic management system for improving traffic flow and collection of environment data. The Two-Phase Event-monitoring and data-Gathering (TPEG) framework is proposed to efficiently monitor traffic events and continuously gather data [5]. In [6], ReFOCUS is developed to dynamically compute the driver's best path according to the average travel time, CO_2 emission, and fuel consumption. In [7], the work focused on security, privacy protection, fog device friendliness (light computations and not much overhead in storage), and easy deployment when developing a secure and intelligent fog-based traffic control light system. The approach in [8] aims at reducing computational tasks in the overloaded RSU cloudlets by utilizing buses as fog nodes. In this work, roadside fog nodes optimally allocates its computational tasks to available and incoming bus fog servers at a lower incentive cost, while maintaining the satisfaction of mobile users.

The study of deploying RSUs was first proposed in [9] and was aimed to aid vehicles in information dissemination in a vehicular network. In [10], the RSU allocation problem is addressed via maximum coverage problem by maximizing the number of unique V2I contacts. [11] used the integer programming framework and considered the effects of buildings, LAN connections, and road topology for minimal deployment of RSUs. In [12], RSU allocation is based on the most popular used routes, the most dominant intersection pairs, and the most critical intersection with the objective of allowing vehicles to update their certificates before it expires.

In this study, we explore how to optimally allocate RSU fog nodes for information sharing given multiple junctions in a city-wide setup. From the empirical mobility traces of taxis plying the city, traffic and communications statistics are derived and analyzed.

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Given these, we propose an Information Sharing via Roadside Unit Allocation (ISRA) strategy for deploying hotspots at road intersections to support various fog computing applications. Our objective is to maximize the amount of information shared between the vehicles and the RSU fog node. In summary, our major contributions are enumerated below.

(1) Based on a seven-day taxi GPS dataset plying on the first and the second rings of Beijing City, the junction's daily average vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) contact densities and space mean speeds are extracted.
(2) In order to determine energy-efficient and information-rich candidate hotspots, we applied an index-coding based transmission scheme to identify the candidate locations' minimum total number of packet transmissions and transmitted data size to satisfy the information demands of nearby vehicles.
(3) Given the empirical findings, ISRA is proposed to identify the optimal positions for the fog centers such that the information shared among vehicles and fog nodes is maximized.

This paper is organized as follows: Section 2 presents the urban city-wide scenario and assumptions. Section 3 discusses the proposed Information Sharing via Roadside Unit Allocation (ISRA) strategy for allocating RSU fog nodes in any of the city's intersections. Section 4 shows the various perfomance metrics to evaluate ISRA. Finally, Section 5 concludes this research study and provides future research undertakings.

2 URBAN CITY-WIDE SCENARIO

Fig. 1 illustrates a section of a city urban grid where there are six junctions and vehicles traversing the city roads. Each colored vehicle corresponds to a specific vehicular density, at a specific sampling time T_S, occupying the road segments connected to the junction. These vehicles have on-board sensors to measure their current surroundings. Road intersections (according to [10]) are the most probable places for situating RSU fog nodes to be used for information dissemination/exchange. The instantaneous V2I contact density (number of transmitting vehicles within the RSU fog node's transmission range) is described in Table 1. It is observed that candidate RSU fog node locations r_1 and r_6 have an increasing number of transmitting vehicles, while r_2 and r_5 experience the opposite. r_4 always has nearby transmitting vehicles, and r_3 has time intervals with and without transmitting cars.

Table 1: V2I contacts at each candidate RSU fog node location in Fig. 1, sampled at each sampling time.

r_j \ T_S	t_0	t_1	t_2
r_1	0	20	30
r_2	30	10	0
r_3	20	0	40
r_4	20	30	40
r_5	20	10	0
r_6	0	10	30

We consider all junctions as candidate locations for allocating RSU fog nodes, and each junction has four road segments. The

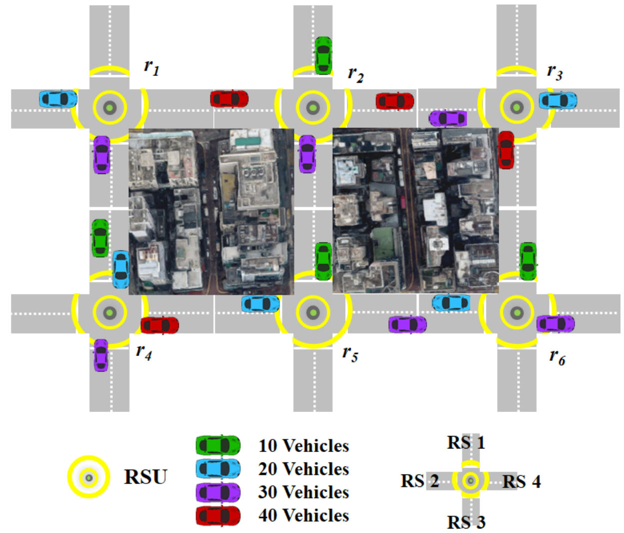

Figure 1: Section of a city-wide scenario having six junctions with various V2I and I2V contact densities.

deployed RSU fog nodes are assumed to be identical, located at the junction's center, and have a transmission range of T_x. Every RSU fog node (r_j) samples its surroundings within every sampling period T_S to check if there are nearby vehicles ready for information exchange. For r_j's with V2I contacts at each sampling time T_S, vehicles send their measurements to the RSU fog node following a scheduled procedure, i.e., according to their arrival. They also send their instantaneous position, speed, and road segment measurement request to the RSU fog node.

After reception, the RSU fog node does the following:

(1) From the instantaneous speed readings, it computes the region's space mean speed to monitor if there are slow moving vehicles staying on the road for a long time [13].
(2) From the vehicular demands, it encodes required road segment measurements for packet transmission.
(3) It broadcasts encoded packets to satisfy all vehicular requests.

The measured environment data to be shared, prior to being sent out by the vehicles to the RSU fog nodes and vice versa, are already compressed, e.g., via Octree compression [14].

There are two modes of broadcast transmission employed by the RSU fog node: 1) Random transmission (RandTrans), and Optimal Index Coding transmission (OptTrans) [15]. RandTrans sends out data from the most to the least demanded road segment information, or based on a uniform distribution if there are equal number of requests of a particular road segment. On the other hand, the OptTrans scheme sends out either the source or encoded packets to satisfy all vehicular demands. Such transmission mode is also able to reduce the file size of the information to be sent, and the number of packet transmissions needed.

Consider sampling time $T_S = t_2$ and road junction r_3. Assume that there are 10 vehicles on each of the four road segments (RS) carrying RS maps m_1, m_2, m_3, and m_4 respectively. The vehicles on

RS 1 request information of RS 2, vehicles on RS 2 require RS 3 information, RS 3 vehicles want measurements of RS 4, and vehicles found on RS 4 demand the information of RS 1. Based on the RandTrans method, the RSU fog node transmits vehicular requests randomly based on a uniform distribution. In OptTrans, the RSU fog node encodes and sends out the following: $m_1 \oplus m_2$, $m_2 \oplus m_3$, and $m_3 \oplus m_4$. The $\oplus$ symbol is the exclusive OR (XOR) operator. Vehicles on RS 1, upon receiving $m_1 \oplus m_2$, will perform $m_1 \oplus (m_1 \oplus m_2)$ to recover its desired road segment measurement m_2. This is also done by the other vehicles located on the other road segments to obtain their desired road segment environment information.

3 INFORMATION SHARING VIA ROADSIDE UNIT ALLOCATION

Transmitted compressed road segment measurements from the surrounding vehicles, such as $m_1, \ldots, m_4$ are called source information, while $(m_1 \oplus m_2), \ldots, (m_3 \oplus m_4)$ are labeled as encoded information. Source information will be transmitted by both vehicles and RSU fog nodes, but encoded information will only be transmitted by the RSU fog nodes.

The amount of information shared (I_{sh}) in the vehicular network depends on the amount of information transmitted by the vehicles (I_v) and the RSU fog nodes (I_j). Therefore, I_v and I_j indicate the amount of V2I and I2V information shared, respectively. This is denoted by

$$I_{sh} = \sum_{v \in V} I_v + \sum_{j \in J} \alpha_j \beta_j I_j \tag{1}$$

In (1), the scheduled uploading of V2I information takes place before the downloading of I2V information. With this scenario, road information at the RSU is first updated by the vehicles, and then the RSU updates the other surrounding vehicles. This information exchange happens within the designated sampling period T_S.

The information sent by the RSU fog node (I_j), depending on the mode of transmission, is either a source packet or an index-coded packet. A transmitted packet has a uniform size and contains one road segment measurement ($\beta_j = 1$), e.g., m_1, or two road segment measurements ($\beta_j = 2$), e.g., $m_1 \oplus m_2$. α_j denotes the number of vehicles in contact with the RSU fog node that received the broadcasted information. We assume all vehicles in contact with the RSU, at a specific sampling time, will share information. Therefore, the amount of information shared increases with the number of V2I contacts within a transmission period.

$$\begin{aligned}
\text{maximize} \quad & I_{sh} && \text{(2a)}\\
\text{subject to} \quad & \sum_{j=1}^{J} x_j \le R,\ x_j \in \{0,1\} && \text{(2b)}\\
& v(x_j) \ge \tau_s,\ \forall j \text{ s.t. } x_j = 1 && \text{(2c)}\\
& \frac{N_{T_j}}{VC_{tot_j}} \le \tau_p,\ \forall j \text{ s.t. } x_j = 1 && \text{(2d)}
\end{aligned}$$

We propose an Information Sharing via Roadside Unit Allocation (ISRA) strategy to optimally determine the RSU locations that will maximize the amount of information shared between vehicles and RSU fog nodes subject to various constraints. The maximization problem is given by (2a) subject to constraints (2b), (2c), and (2d).

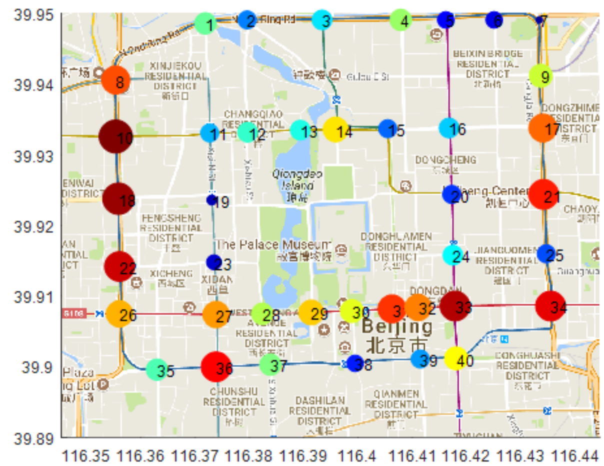

Figure 2: The 40 candidate RSU fog node allocations. The color and size of the circle highlights the average V2I contact density at each junction.

In constraint (2b), R is the maximum number of roadside units to be deployed. If a candidate intersection r_j is chosen, $x_j = 1$, otherwise, $x_j = 0$.

In constraint (2c), the function $v(x_j)$ computes the RSU r_j ($\forall x_j = 1$) region's space mean speed derived from the surrounding instantaneous vehicular speeds, v_t. Based on the computed value, the junction that has a space mean speed equal to or over a threshold speed limit, τ_s, is selected. This is important especially when there are too many cars willing to share information to the RSU fog node, and the RSU fog node's memory capacity or computational power is exceeded. This constraint, thus, balances the communication load of each selected RSU. In case a chosen candidate location runs out of computational power or storage, vehicles in the vicinity will be able to transfer to other RSU fog nodes for information dissemination.

Finally, constraint (2d) discriminates selected intersections based on a junction's transmission density threshold τ_p. Transmission density is defined as the total number of transmissions needed by RSU r_j to satisfy a set of demands by a given number of V2I contacts (VC_{tot_j}) per sampling period. This constraint restricts the energy consumption for delivering information to the vehicles.

A higher(lower) threshold value for constraint (2c)((2d)) dramatically reduces the number of possible locations where the hotspots can be allocated.

4 SIMULATION STUDIES AND DISCUSSION

In this section, we present how useful information from empirical taxi mobility traces are extracted and used by ISRA to allocate hotspots for maximum information sharing between vehicles and RSU fog nodes. We use realistic 3D point cloud data found in [16] to represent the static information of all road segments of a junction shared by the vehicles and RSU fog nodes.

4.1 Empirical Findings from Mobility Traces

We investigated a seven-day dataset of mobility traces of 28,590 taxis plying the City of Beijing. The dataset contains the taxi's ID number, location's GPS coordinates, and its timestamp [17].

We studied 40 junctions from the first two inner rings of Beijing City and these are shown in Fig. 2. The separation between two adjacent road intersections is at least 400 m. The light and small colored circles (colors approaching blue) depict a low volume of V2I contacts, while large dark colored circles represent the opposite. The V2I contacts of each RSU r_j, VC_j, are sampled every $T_S = 2$ min with the transmission range T_x set to be 200 m. $j = 1, 2, \ldots, 40$. The numerical values of the V2I contacts of each junction are seen in the top portion of Fig. 3.

To compute for the junction's space mean speed, we first calculated the instantaneous speed, v_t by:

$$v_t = \frac{GPS_t - GPS_{t-1}}{t_s} \tag{3}$$

where GPS_t and GPS_{t-1} are the vehicle's current and previous GPS locations, respectively, converted to distance using the Haversine formula [18]. Each GPS update is taken every $t_s = 10$ s. The space mean speed for each junction, using v_t, is computed according to [13] and are shown in the bottom part of Fig. 3. It is noticeable that the daily space mean speed value for each considered junction is below the normal speed limits for most urban roads. This observation highlights that there is mostly traffic congestion throughout the day, even if there are fewer vehicles on the road, e.g., junction 23.

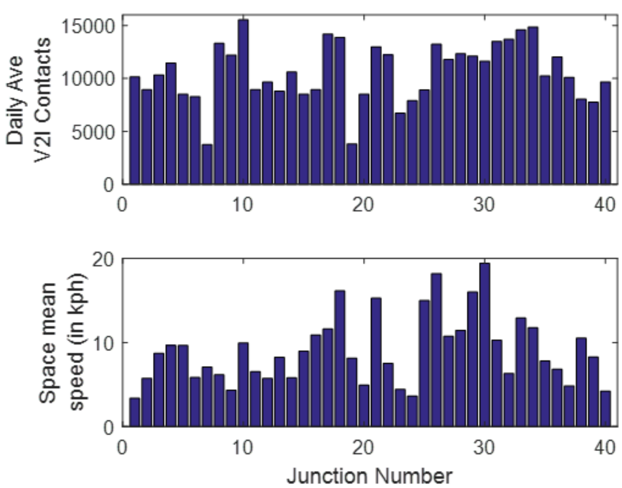

Figure 3: Empirical findings for the chosen 40 possible roadside unit locations around the first and second rings of Beijing City averaged over the 7-day period.

To obtain the candidate RSU fog nodes r_j's total number of transmitted packets (NT_j), the OptTrans scheme is employed [15] and compared to the RandTrans. The transmitted packet size is 1024 bytes, where 1000 bytes correspond to the payload and the remaining 24 bytes are for the overhead. The benefit of using OptTrans over RandTrans is illustrated in Fig. 4. It is evident that the optimal index coding transmission scheme guarantees that the total number of packet transmissions and transmitted data size are minimized while satisfying the demands of all nearby vehicles. Given these, the number of packet transmissions employing the OptTrans scheme will be used in constraint (2d).

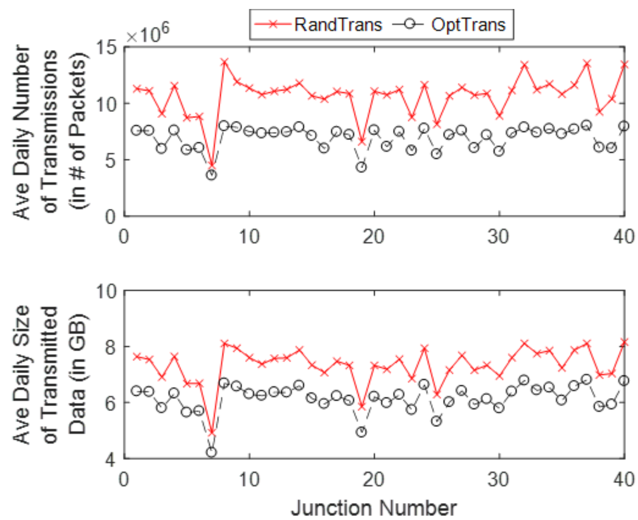

Figure 4: Total number of transmitted packets (top part) and transmitted data size (bottom part) for the chosen 40 possible roadside unit locations around the first and second rings of Beijing City employing the RandTrans **and** OptTrans **schemes.**

4.2 Performance Evaluation

During the simulations, the following threshold values are set. R is set to 10 to limit the number of deployed RSU fog nodes around the two rings of Beijing City to 25%. τ_s is set to 10 kph, which is approximately half the maximum space mean speed allowed by any candidate location. Finally, we make τ_p equal to 1, such that on average, the RSU fog node satisfies one vehicle per transmission.

We first compare how the mode of transmission affects the amount of I2V information shared, since the number of packet transmissions required by the OptTrans scheme to satisfy the vehicular demands is approximately equal to two thirds of that required by the RandTrans method according to Fig. 4. Fig. 5 shows that OptTrans allows more sharing of information when compared to RandTrans, even if there is less packet transmission and fewer transmitted data size. This is due to the fact that OptTrans often sends encoded packets with doubled amount of information. Given the results presented in Figs. 4 and 5, we decide to employ OptTrans with the proposed ISRA strategy in the following.

The ISRA strategy is then compared to three other deployment methods described as follows:

(1) Downtown-based Deployment (DRSU) [19]: More RSUs are deployed in low-density areas and less in high-density places. 60% of the total number of RSUs to be deployed should be located in low-density areas.

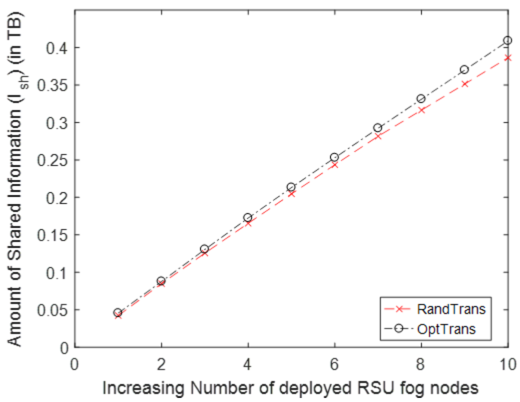

Figure 5: Comparing the amount of I2V information shared when using two modes of transmission.

(2) Critical Intersections Deployment (CritInt) [20]: This uses a cross-road rank algorithm to determine critical intersections in Beijing City. It ranks the candidate junctions based on the eigenvector centrality measure that factors the effects and relationships of the origin-destination pairs, irreplaceable paths and the junctions involved. The RSU fog nodes, according to their findings, are deployed at junctions 2, 4, 8, 10, 18, 21, 26, 27, 33, and 34.

(3) Distinct Vehicles Deployment (DistVeh) [10]: Candidate locations are chosen based on the number of unique taxi IDs in contact with an RSU, i.e., the 10 RSUs with the most number of unique taxi IDs are selected as the candidate locations. The RSUs are deployed to maximize the number of distinct vehicles having at least a single V2I contact based on vehicular trajectories. This is done for collection and dissemination of unique traffic announcements. In this study, these are found at candidate locations 10, 17, 18, 21, 22, 31, 32, 33, 34, and 36.

The top figure of Fig. 6 illustrates that ISRA outperforms the other three allocation schemes to maximize the amount of shared information between vehicles and infrastructure nodes. Notice that all allocation methods have the same monotonically increasing trend as the number of RSUs increases. ISRA captures both the characteristics of CritInt and DistVeh, i.e., (1) identifying most of the critical junctions even by only considering the space mean speed and transmission density, and (2) locating junctions that maximizes the number of V2I contacts coming from distinct vehicles. ISRA also avoids the disadvantage provided by DRSU in terms of sharing information in the vehicular network by allocating a fixed amount of RSU fog nodes in certain areas.

We also compare in terms of the percentage change of information shared when ISRA is applied in the simulated city-wide scenario. This is shown in the bottom figure of Fig. 6. On average, ISRA has approximately 6%, 10%, and 47% more shared information than DistVeh, CritInt, and DRSU, respectively. As more RSU fog nodes are being deployed, the behaviors of CritInt and DistVeh approach that of the ISRA strategy.

The energy efficiency (*EE*) of each of the deployment methods are also evaluated. We define *EE* in (4).

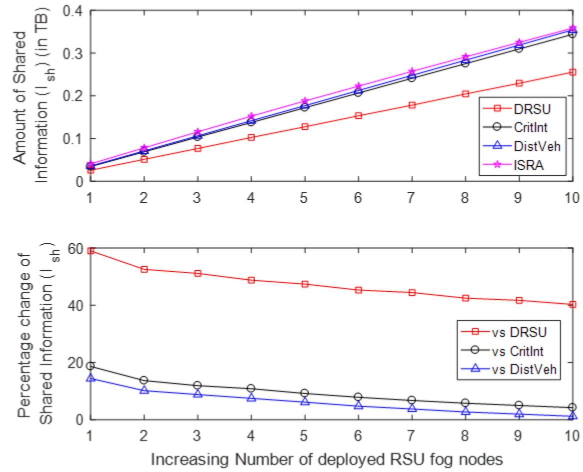

Figure 6: The amount of information shared (I_{sh}) using four deployment methods (top figure) and the percentage change of information shared (I_{sh}) provided by ISRA against the other three deployment methods (bottom figure).

$$EE = \left[1 - \gamma\left(\frac{\sum_{j=1}^{J} NT_j}{I_{sh}}\right)\right] * 100\%, \forall x_j = 1. \quad (4)$$

where $\gamma = \frac{\text{Byte}}{\text{\# of packets}}$ is a unit correction factor.

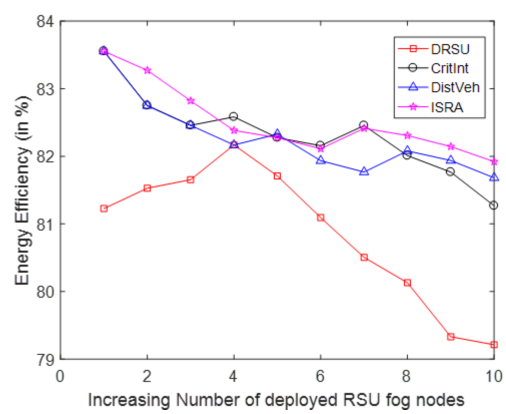

Figure 7: The energy efficiency of the four deployment methods.

A deployment method is energy-efficient if the chosen RSU fog node locations are able to share the most information using the least number of packet transmissions. The energy efficiency for each deployment method is shown in Fig. 7. Generally, ISRA has a higher energy efficiency (average of 83%) compared to the other three deployment methods. For DRSU, the decrease of its energy efficiency is affected by the deployment of RSU fog nodes at low-density junctions.

Finally, Fig. 8 shows how much information is shared by each selected RSU fog node in each deployment scheme. It is evident that ISRA balances the information sharing between the deployed RSUs. ISRA, by considering the region's space mean speed, allows the offloading of vehicles to nearby RSU fog nodes such that the system's computational power and memory capacity will not be exceeded. Such capability allows ISRA to virtually interconnect all deployed RSU fog nodes and maintain RSU fog nodes in the vicinity to operate at roughly the same rate.

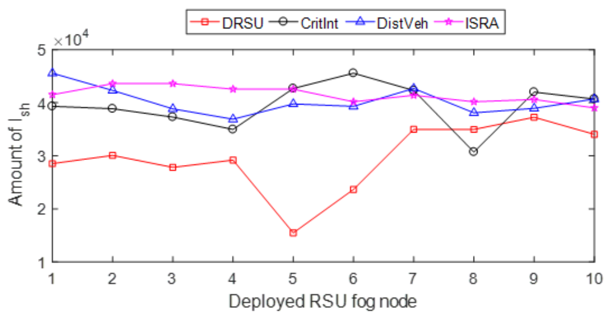

Figure 8: ISRA balances the information shared between the deployed RSU fog nodes. (For ISRA, deployed RSU fog nodes 1-5 and 6-10 are groups of adjacent RSU locations.)

Therefore, supported by Figs. 6 - 8, ISRA outperforms the other three deployment methods by being able to allocate RSU fog nodes in energy-efficient and information-rich junctions, while at the same time, able to balance the load (shared information processing/storage) among all deployed RSU fog nodes.

5 CONCLUSION AND FUTURE WORK

In this study, we have proposed an Information Sharing via Roadside Unit Allocation (ISRA) strategy for deploying RSU fog nodes in a city-wide context to maximize the amount of information being shared among vehicles and RSU fog computing hotspots. To do this, empirical findings from taxi mobility traces plying the City of Beijing are used. ISRA allocates RSU fog nodes to city intersections that are information-rich and energy-efficient. Given a constraint of deploying 10 RSU fog nodes in Beijing City, ISRA enjoys a 6% increase in the amount of information being shared compared with the best conventional scheme, which is equivalent to about 4 GB more of shared information. Also, ISRA achieves an 83% energy efficiency that translates to fewer packet transmissions needed for sharing more information to the surrounding vehicles. Finally, ISRA is able to balance the information sharing among deployed RSU fog nodes, such that in practice, all deployed RSU fog nodes can operate at similar computational power and memory consumption.

For the future work, the proposed ISRA strategy will be enhanced to cover an entire city. The enhanced ISRA will also include bus stops in its analysis to determine possible effective junctions where RSU fog nodes can be deployed. Furthermore, the optimization problem will consider other important factors, such as the inclusion of dynamic data exchange and various additional constraints like latency and transmission throughput.

6 ACKNOWLEDGMENT

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