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Efficient Dynamic Communication Method According to Vehicle Density in Smart Traffic Environment

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Abstract.
A smart traffic environment is an environment in which all structures, vehicles and people connected to a vehicle can transmit and receive mutually necessary information at any time. In such an environment, the vehicle user can receive the desired information accurately and quickly, and real-time data processing can be carried out on a safe and comfortable road. Especially, in the smart traffic environment, it is important to find the surrounding objects in real time because the surrounding objects cannot be fixed in real time and the types of surrounding objects and communication conditions can be changed continuously. When searching for nearby objects, if the communication situation is bad, data retrieval technology considering the density of surrounding objects is required because data loss and energy consumption of the vehicle sensor can be large. In this paper, we analyze the delay time according to vehicle density in a star - shaped communication network as a cornerstone for real - time communication construction considering vehicle density. In addition, in this paper, we construct a simulator for the experiment, analyze it according to the degree of each communication cycle, and derive the result accordingly. The result of this paper is expected to be the cornerstone of communication technology for constructing safe and comfortable driving environment as essential technology of smart traffic.

Keywords: Smart Traffic, Dynamic Communication, Neighbor Discovery Protocol, Cost of energy (COE)

INTRODUCTION

In the past traditional transportation section, it is difficult to manage aged roads and structures because CCTV monitoring team who monitors lots of road web CCTV in the real time manages massive structures without considering recent IT technology convergence. Through these reasons, the incidence rate is very high.

However, because of recent remarkable advances in science technology, it is possible to monitor CCTV using automatic monitoring system in the real time. Then, if monitoring system gets unexpected situation, it directly give event information to people. In this environment, there are various services such as autonomous driving system and big data. These technologies are part of Smart city. Smart city means IT convergence city which consists of infrastructure and ICT technologies. In this city, mutual information can be shared between objects [1]. Therefore, in smart city, people can easily get the information they want whenever and where they want, and share information about all things around them with their neighbors.

Smart city is composed of smart energy, smart water, smart transportation, smart building, and smart governance. Smart water reduces a waste of water using water management system. Similar, Smart energy integrates and manages the energy systems of each building in the city. Smart car is an integrated system that provides safe and pleasant driving environment by exchanging information between cars and infrastructures. Smart building automatically controls all the objects such as electronic devices, lights, and security door system to reduce energy consumption. Lastly, Smart governance permits too many rules and regulations related to smart city.

In Smart city, the ratio of smart traffic is more than 50%. So, Smart traffic is a top priority service among smart city objects such as smart energy, smart water, smart transportation, smart building, and smart governance.

In the existing smart traffic, intelligent transport systems (ITS) [2] provides diverse services based on transit time, traffic volume, speed, occupancy, and image collected by AVI (Automatic Vehicle Identification, VDS (Vehicle Detection System), CCTV (Closed Circuit Television), VMS (Variable Message Sign), DSRC (Dedicated Short Range Communication). Then, it uses one-way communication. However, smart traffic needs two-way communication to share real-time information with car, road, and people. In order to communicate each other, they firstly need to find their neighbors. Especially, unlike previous transport system, smart traffic considers additional information such as traffic volume and communication cycle.

In order to obtain information about neighboring object quickly in smart traffic, the neighbor discovery protocol (NDP), which is widely used in sensor network environment, can be utilized. If objects use NDP to setup network at initial time, they quickly find their neighbors within their communication range to connect each other. If a network between objects cannot be established at initial time, it is impossible to transmit and receive packets each object. Therefore, NDP is essential for Smart traffic.

In this paper, we propose a recommendation algorithm of communication cycle based on vehicle density to reduce latency and energy consumption. For this purpose, we implement smart traffic simulator and experiment to analyze system performance.

RELATED WORK

Beginning with the establishment of the national basic plan, basic transport system provides limit services because lot of information is not shared due to divided network and one-way communication. For example, when cars only pass under smart traffic system, system manager get the information. However, in smart traffic, there are many challenges when applying existing ITS to smart traffic environment without change.

To overcome these limitations, in February 2013, the government plans to develop road safety assessment techniques and improve the risk, as well as introducing C-ITS to share information on vehicles, vehicles and roads. After that, the government plans to establish a C-ITS standard by May, establish an infrastructural plan in October, and implement a pilot project in 2014 [12].

In addition, the 2020 Plan for Automobile Road Traffic Intelligent Transportation System specifies the policy goals and plans of the "safe road traffic without traffic accidents by the real-time monitoring system" in order to detect the causes of traffic accidents such as bad weather, construction or unexpected situation. It has shown plans to expand practical use of active safety services and to expand the supply through area management services and data sharing between roads, vehicles, and people [13].

However, there is still a lack of research on smart transportation in the government's efforts. In this paper, we study NDP which is the first step of network construction in smart traffic environment.

The NDP is a protocol that is performed at the initial stage of inter-object communication. It can search for other objects in real time by referring to specific objects. The connection time of the network communication and the energy consumption of the object are changed according to the time of searching for the early object. [7][8][9] are a field that has been studied classically in the field of sensor networks. However, most of them deal with fixed environment, and research on dynamic environment such as smart traffic is lacking.

Smart traffic must consider the density of cars because the density and type of objects change in the real time. In order to communicate with infrastructure built on the road, we consider smart topology that center node manages all the objects. If preliminary studies on the performance of communication between infrastructure and vehicle are not conducted, the initial network construction time becomes long, and it becomes difficult to provide accurate service due to communication paralysis and inaccurate data sharing.

In this paper, we analyze the traffic flow model in advance to understand the relationship between vehicle density and communication performance, and analyze the density, delay time, and energy consumption of the vehicle based on the analysis results. The results obtained in this paper can be applied to various applications such as Team integration system [3], DriveC2X platform [4], reindeer accident prevention system [5] and RASTU safe operation service [6].

TRAFFIC FLOW MODEL OF SMART TRAFFIC

In this chapter, traffic flow model of smart traffic is examined. In general, traffic volume, speed, and vehicle density are mutually compatible values. It is called traffic flow model.

The traffic flow model can be classified into a single section model and a multiple section model. There are Greenshield model, Underwood model, Ellis model, and Greenberg model. In this paper, the relationship between speed and vehicle density is analyzed using the Greenberg model, which deals well with complexity and accuracy. Then, the modified Greenberg model [10][11] is used in order to prevent the speed increase to infinity in the low vehicle density region which is a disadvantage of the Greenberg type.

The basic Greenberg model can be used to find the relationship between speed and vehicle density using equation (1) as follows:

$$u = u_m \times \ln\left(\frac{k_j}{k}\right) \tag{1}$$

In equation (1), u means the vehicle speed (km/h), u_m is the critical speed (km/h), k_i means the congestion density (vehicle/km), and k means the vehicle density. Then, the critical speed means the speed when the vehicle is congested on the road. Similar, the congestion density means the density when the traffic congestion occurs. However, in the case of the basic Greenbarg model, as the density value of denominator k becomes smaller, the value of congestion density becomes larger. As a result, there is a disadvantage that an infinite speed can be obtained when the vehicle density is reduced. In order to solve these drawbacks, this paper used the method of determining the maximum speed of the vehicle when a vehicle density below a certain level as shown in Equation (2).

$$u = \begin{cases} u_q & \text{if } k \leq 10 \\ u_m \times \ln\left(\frac{k_j}{k}\right) & \text{if } k > 10 \end{cases} \tag{2}$$

In Equation (2), u_q means the maximum speed of the vehicle. The remaining parameters are the same to Equation (1). In Equation (2), if the vehicle density is less than or equal to 10, the speed value is the highest speed of the vehicle or the existing Greenberg-type model is used.

In this paper, we consider the headway distance in addition to the existing traffic flow model. The headway distance can be obtained from Equation (3), which means the distance from the front end to the back end of the vehicle body.

$$s = \frac{1000}{k} m \tag{3}$$

In equation (3), k is the density of the vehicle, and s is the headway distance. Figure 1 is X-Y-Y graph showing the relationship between the density of the vehicle and its speed and headway distance using the modified Greenberg model. In Figure 1, the X axis represents the density of the vehicle, the left Y axis represents the vehicle speed, and the right Y axis represents the distance between the cars. In the early 0-10 vehicle/km section of the vehicle, there is no change in the speed of the vehicle and the distance between the cars, and the speed of the vehicle is fixed at 100m in the case of the interval of 120 km/h. However, when the density of the vehicle exceeds 10, it can be seen that the speed of the vehicle is reduced. Specifically, the speed of the vehicle decreases linearly while the distance between the wheels decreases exponentially. It can be seen that the speed and density of the vehicle intersect with the vehicle's density of 65 vehicle/km. That is, the speed of the vehicle is reduced even though there is almost no change in the headway distance. Using these correlations, we will look at the results of dynamic communication techniques in the next section.

Figure 1 is a graph showing the relationship between the density of the vehicle and its speed and headway distance using the modified Greenberg model.

In the X-Y-Y graph, the X axis represents the density of the vehicle, the left Y axis represents the vehicle speed, and the right Y axis represents the distance between the cars. In the early 0-10 vehicle/km section of the vehicle, there is no change in the speed of the vehicle and the distance between the cars, and the speed of the vehicle is fixed at 100m in the case of the interval of 120 km/h. However, when the density of the vehicle exceeds 10, it can be seen that the speed of the vehicle is reduced. Specifically, the speed of the vehicle decreases linearly while the distance between the wheels decreases exponentially. It can be seen that the speed and density of the vehicle intersect with the vehicle's density of 65 vehicle/km. That is, the speed of the vehicle is reduced even though there is almost no change in the headway distance. Using these correlations, we will look at the results of dynamic communication techniques in the next section.

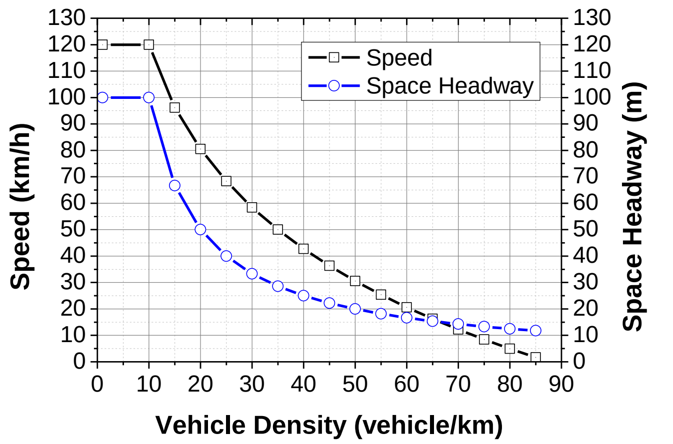

Figure 1: Relationship of speed, space headway, and vehicle density

EXPERIMENTAL ENVIRONMENT

In this section, we describe the configuration of experimental environment for efficient dynamic communication according to vehicle density in smart traffic environment.

Vehicles in the smart traffic environment are equipped with wireless communication functions and can transmit/receive at any time with surrounding objects through tiny sensors. Because sensors operate on tiny batteries, unnecessary system structure or frequent transmission and reception can lead to short sensor life. Therefore, various techniques are required to increase the sensor life.

In this paper, we assume that a small sensor is attached to a vehicle in a smart traffic environment. It is assumed that the sensor attached to each vehicle carries out communication using CC1000 communication module and each sensor uses CSMA / CA method to prevent data collision.

In the case of network topology, communication is performed by configuring star topology that each vehicle communicates with one infrastructure like VDS. We assume that the communication range between the infrastructure and the vehicle is 28 * 100 m. Moreover, in this situation, an infrastructure search neighbors like cars within communication range.

The vehicle density is assumed from 10 to 80 vehicles/km based on the analysis in Section 3. The data of each sensor is assumed to be 53 Kbytes and the event trigger time is 15 ms.

The duty cycle, which means the frequency of actual communication, is set to 42% and 10% because our scheduling uses BIBD-based NDP which has duty cycles from 1 to 42%. Duty cycle means the ratio of the time that the sensor turns on the switch to perform communication. For example, if the system is operating in 100s to 10s, but not in the remaining 90s, then the system's duty cycle is 10% = 10/100.

Figure 1 shows the experimental environment picture assumed in this paper. In Figure 1, the overall box size is shown as 28 * 100m, and the density of the vehicle increases as it goes to the right. Also, it can be seen that communication is performed by constructing a star type topology between the right structure and the vehicle.

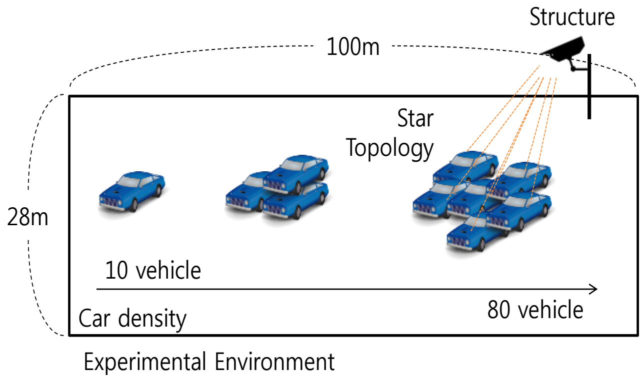

Figure 2: Experimental Environment in Smart Traffic

In this paper, we assume a slotted network environment in which each vehicle transmits data at intervals of 15 ms and the time axis is divided into slots. Therefore, assuming that each vehicle transmits data after 100 seconds, 1.5s = 15ms * 100s. And if we assume a 10% duty cycle, it means to transmit 10 data per 100 slots, which means that we will send a total of 10 data in 1.5 seconds.

Table 1 shows the specific parameter values of the experimental environment assumed in this paper. The first column in the table is the name of each attribute, and the second column is the value of each attribute. In the next section, we will look at the results of actual simulation based on the experimental environment assumed in this chapter.

Table 1: Properties and Values for Simulation Setting

Properties	Values
Network Topology	Star Topology
Experimental Area	$28 \times 100m$
Radio Module	CC1000
Car Density	10,20,30,40,50,60,70,80
Event Trigger Time	15ms
packet size	53 bytes
Duty Cycles	42%, 10%

EXPERIMENTAL RESULT

Figure 3 is a graph showing the minimum, maximum, and average delay time according to the vehicle density when the communication duty cycle is 42%. The trend of the graph shows that as the density of the vehicle increases as a whole, the delay time becomes longer. In particular, it can be seen that the delay time increases sharply at a point where the intersect point between the headway and the vehicle speed is 60 density. Through this fact, we know that the delay time is shorter where the vehicle density is less than 60. That is, in the case where the vehicle density is less than 60, a duty cycle of 42% does not cause a problem in communication, but there is a disadvantage that communication cannot be performed well at a point where the vehicle density exceeds 60.

Table 2: Experimental Result of Latency at Duty Cycle 42%

Density	Max	Avg	Min
10	0.27	0.15	0.05
20	1.53	0.37	0.06
30	2.47	0.52	0
40	5.02	0.81	0
50	10.26	1.52	0
60	12.83	2.64	0
70	23.24	3.33	0
80	58.04	3.95	0.06

Table 3: Experimental Result of Energy Consumption at Duty Cycle 42%

Density	Energy
10	6.89
20	39.58
30	64.03
40	130.27
50	267.3
60	335.76
70	607.07
80	1516.62

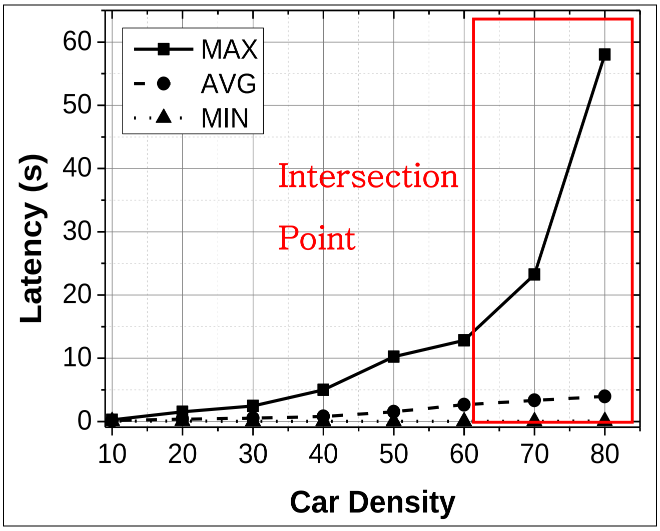

Figure 3: Experimental Environment in Smart Traffic

Figure 4 shows the energy consumption of sensor devices depending on vehicle density in a communication environment with a duty cycle of 42%. Similar to the results in Figure 3, it can be seen that the energy consumption increases sharply at the point where the vehicle density exceeds 60. It can be seen that the energy consumption is 3 times worse than the vehicle density of 60 at a vehicle density of 80 points.

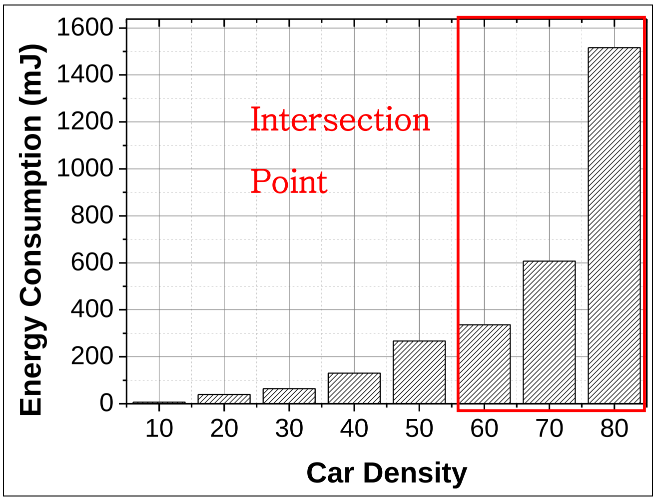

Figure 4: Experimental Environment in Smart Traffic

Figure 5 shows latency distributions of the delay time according to the vehicle density at 10% of the communication duty cycle. In the pattern similar to Figure 3, it can be seen that the delay time of the vehicle rises rapidly from 60.
However, unlike the duty cycle of 42%, it can be seen that the ratio of increasing the vehicle density from 60 is higher than that of 70. Also, at car density 80, which has the highest vehicle density, 10% duty cycle is lower latency than 42%. The reason is that duty cycle 42% has shorter communication cycle than 10%. It bring higher data collision.

Table 4: Experimental Result of Latency at Duty Cycle 10%

	Max	Avg	Min
10	3.11	1.26	0.25
20	3.48	1.23	0.25
30	9.81	1.51	0.09
40	11.9	2.05	0.19
50	13.15	2.38	0.2
60	16.59	2.56	0.15
70	33.77	3.61	0.01
80	44.85	4.46	0.2

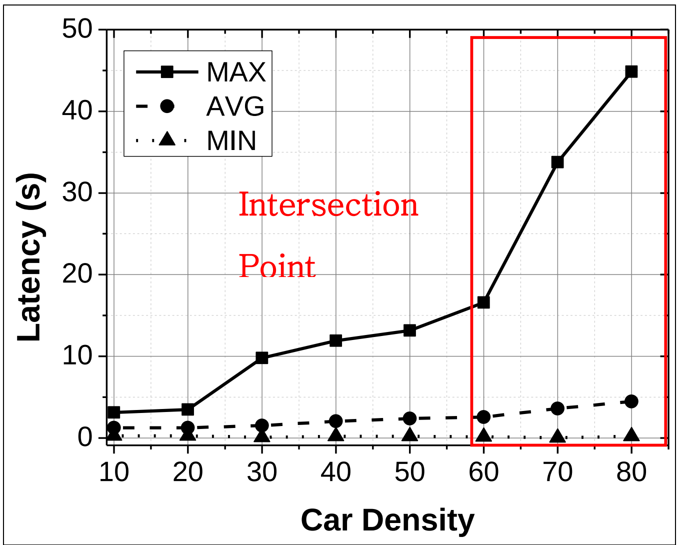

Figure 5: Maximum, Average, Minimum Latency each Car Density at Duty Cycle 10%

Figure 5 shows the energy consumption of the sensor in a 10% duty cycle communication environment. It can be seen that the overall duty cycle 10% energy consumption is less than the 42% duty cycle in the remaining vehicle density range except the vehicle density 10. The reason is that sensor nodes with duty cycles 10% wake up at a probability of 1/10 for data communication. On the other hands, sensor nodes with duty cycles 42% wake up at a probability of 3/7 for data communication. A large number of data communications means a large amount of sensor battery consumption. Therefore, it can be seen that the 10% duty cycle at which the sensor occurs at a low frequency is better than the 42% duty cycle in terms of energy consumption. At duty cycle 80, 10% duty cycles are about 5 times more energy efficient than 42%. From these results, we can see that the overall duty cycle 10% is more dominant than energy consumption of 42% duty cycle. Similar to the reason shown in Figure 4, the duty cycle is 42% and star topologies have longer delays due to frequent collisions, resulting in higher energy consumption.
Figure 6 is a graph of sensor energy consumption when using a 10% duty cycle and 42% combination algorithm. That is, based on the above analysis, a duty cycle of 42% is used at less from a vehicle density of 60, and a duty cycle of 10% is used at a vehicle density of 60 or more. If the combination algorithm is used for data communication between vehicles, the delay time can be reduced by avoiding the delay time due to the packet collision when the density of 42% duty cycle is high. Figure 6 shows that when the vehicle density is 80, the delay time does not go up to 58s but is less than 45s. When the combination algorithm is used as described above, it is possible to reduce the delay time for packet transmission in quick response to the vehicle density.

Table 5: Experimental Result of Latency at Duty Cycle 10%

	Energy
10	20.1
20	22.63
30	64.24
40	78.1
50	86.28
60	108.88
70	222.26
80	295.41

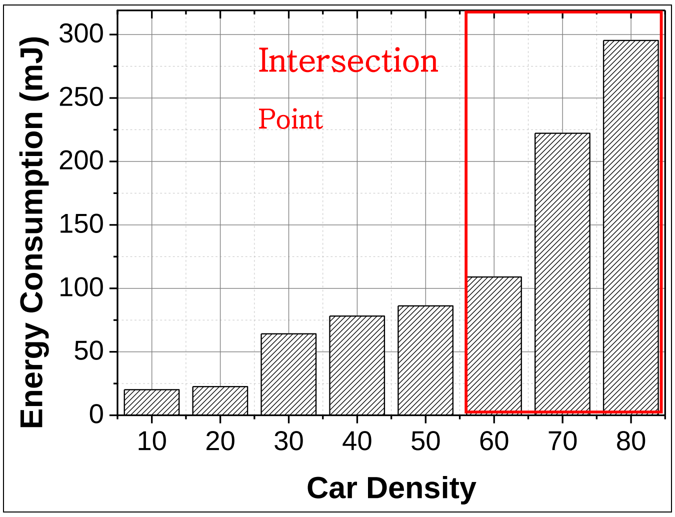

Figure 6: Energy Consumption each Car Density at Duty Cycle 10%

Figure 8 shows the energy consumption of the combination algorithm. It is seen that the energy consumption is reduced when the density of the initial vehicle is increased to 60, and then the energy consumption is decreased to 70. This is because the combination algorithm changes to a 10% duty cycle algorithm starting from 70. That is, a 10% duty cycle with a density 70 would consume less energy than a density 60 because the energy consumption is less than 42% duty cycle. Similarly, the energy consumption of density 80 is also lower than that of density 60.
In this paper, based on the simulation results, it can be seen that the delay time and the energy consumption are rapidly increased based on the point where the vehicle density is 60, which is the intersection of the vehicle speed and the headway distance. Also, it was found that the delay time is lower even in a communication environment having a low duty cycle based on a vehicle density of 60. In conclusion, it can be seen that the communication technique utilizing the duty cycle having a high frequency is advantageous in an area where the vehicle density is moderately low, and the technique using the duty cycle having a low frequency is superior in the area

having a high vehicle density. Although there is a duty cycle required for each smart traffic application, based on the study of this paper, each application can perform better in comparison with the conventional one if the duty cycle is changed when necessary in a smart traffic environment. In other words, constructing a dynamic system according to vehicle density makes it possible to construct a communication system with low latency and efficient energy consumption.

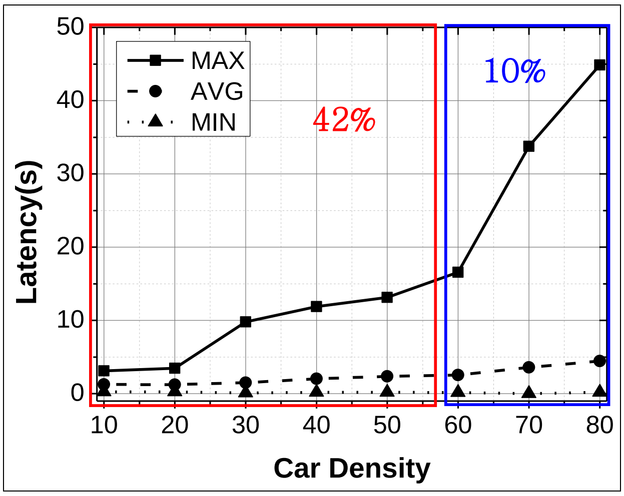

Figure 7: Maximum, Average, Minimum Latency each Car Density at Fusion of Duty Cycle 10% and 42%

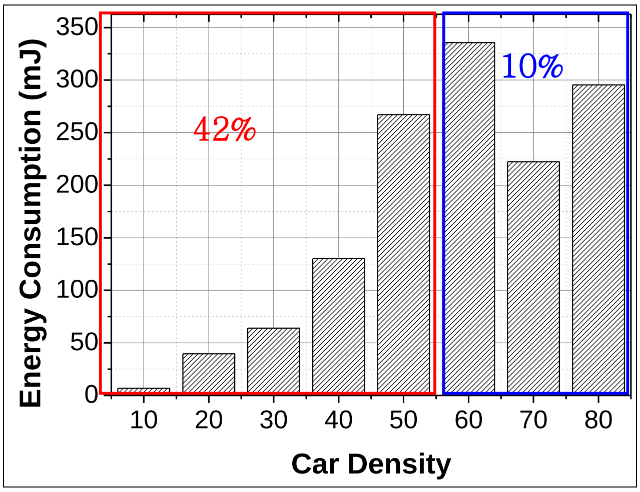

Figure 8: Energy Consumption each Car Density at Fusio of Duty Cycle 10% and 42%

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CONCLUSION

Future roads will have many smart vehicles and communication between each vehicle will be possible. A vehicle capable of communicating must prioritize the vehicle before it communicates with the surrounding vehicle, and the speed of discovery is directly related to the life of the sensor. In this paper, we investigated Car Density, Latency and energy consumption as an initial study on smart vehicles. Basically, 42% of the duty cycle is thought to be always faster than 10%, but the actual experiment shows that the duty cycle of 10% is advantageous compared to the duty cycle of 42% at the point where the car density is 60 or more. Based on these experimental results, we propose a fused algorithm and show that the proposed algorithm has better latency and energy consumption than the existing fixed algorithm.

Based on the experimental results, the research group will analyze the communication environment considering more factors in the smart city environment in the future, and plan to conduct detailed research on the linkage with other fields.

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