# Relay by Smart Device: Innovative Communications for Efficient Information Sharing Among Vehicles and Pedestrians



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# Relay-by-SmartDevice: Innovating V2P, V2V, and P2P Communications for Efficient Information Sharing Among Vehicles and Pedestrians

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*The combination of vehicles and mobile computers such as smartphones and wearable devices has provided many applications in our daily life. However, it is still limited to the applications in personal use. In fact, by utilizing the device-to-device technologies, which make use of the mobile device resource, vehicle-to-pedestrian (V2P), vehicle-to-vehicle (V2V) and pedestrian-to-pedestrian (P2P) communications can be more effective and convenient. In this article, we present a concept of Relay-by-SmartDevice that aims at information dissemination by smart communication devices, which can contribute to efficient information sharing among vehicles and pedestrians. We propose a novel technique for effectively forming and disbanding the groups of vehicles and pedestrians for their communications. The proposed mechanism is based on three criteria, namely the Stability of the group, the Activity of the group, and the Qualification as a group leader. Procedures for group forming and disbanding are introduced. We develop a prototype as a smartphone application using WiFi technology, referred to as the second generation of Relay-by-Smartphone, which is the smartphone type of Relay-by-SmartDevice. The results of the field experiment show that the proposed group based information sharing technology has a good potential to be utilized in V2P, V2V, and P2P communications.*

## Introduction

Vehicular communication networks have been improving the convenience of human transportation and have become an indispensable technology nowadays [1], [2]. On the other hand, the wide spread of mobile computers, such as smartphones and wearable devices, has encouraged the industry to integrate such devices with vehicles, especially with cars [3-7]. Therefore, when the vehicles such as cars, buses, or even trains move, they can still communicate with people who have mobile computers. It has provided us with daily life applications such as navigation, controlling vehicles, estimating traffic, transporting services, and so forth. However, most of the existing works only consider the combination of a single device and a single vehicle for Vehicle-to-Pedestrian (V2P) safety systems or personal use. Communication among multiple vehicles and mobile devices of pedestrians has not received adequate attention even though it is promised to be the most effective method for locally exchanging the wide variety of information, which can be used in early crash detection, congestion avoidance, commercial advertisement, entertainment, and so forth.

One of the typical applications that require the existence of communication networks connecting vehicles and pedestrians is real time navigation in disaster-stricken areas where communication network infrastructures are heavily destroyed while the conditions of road infrastructures and traffic flows are totaly different from those in usual days. In the Great East Japan Earthquake and Tsunami in March 2011, in fact, disaster-stricken people were unable to expeditiously escape from a tsunami due to traffic jam. In order to resolve the post-disaster traffic congestion problem, real time navigation must be provided from just after the impact of earthquake and before the Tsunami arrives. Forming ad hoc networks by using cars and people locally and connecting them together even intermittently is the one and only possible communication method for getting/providing valuable information for real time navigation.

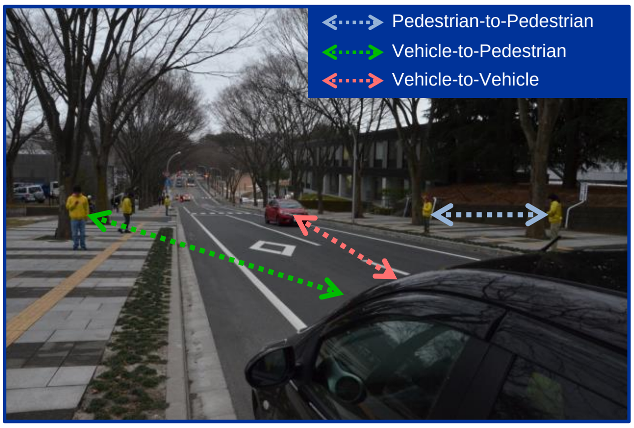



***Figure 1** The coexistence of V2P, V2V, and P2P communications in the same field.*

To realize a dynamic and flexible network consisting of vehicles and pedestrians, some key technologies have to be employed in order to overcome the relevant challenges derived from an extreme difference in mobility property between vehicles and pedestrians. In other words, the coexistence of V2P, Vehicle-to-Vehicle (V2V) and Pedestrian-to-Pedestrian (P2P) communications in the same field, as shown in Figure 1, makes it more difficult to construct appropriate networks for efficient information sharing. To this end, in this article, we propose an intermittent group based information exchange technology where vehicles and pedestrians dynamically form and disband groups according to situations. Furthermore, we present the results of field experiments conducted by using the prototype, referred to as the second generation of Relay-by-Smartphone, which is the smartphone type of Relay-by-SmartDevice. The key functionalities

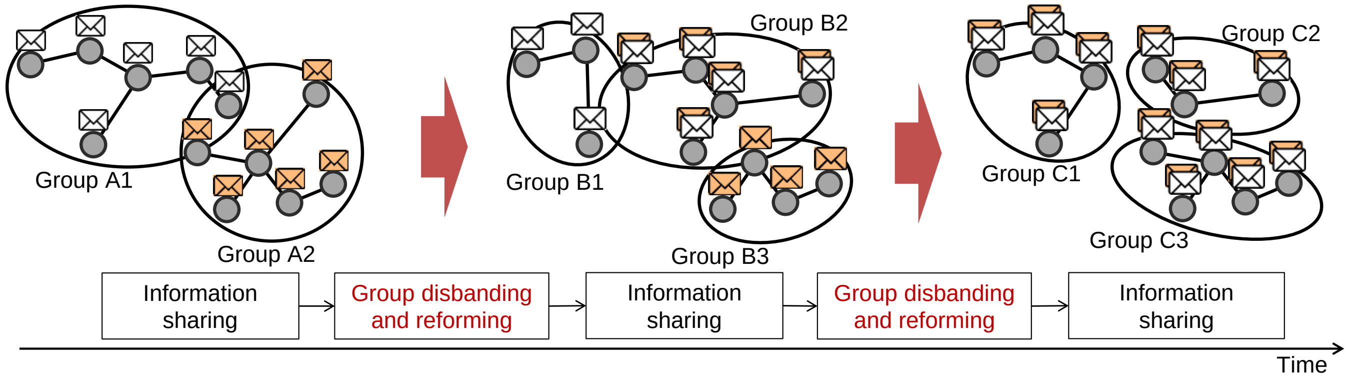



***Figure 2** Example of the envisioned process.*

of the proposed techniques are implemented in the prototype as a smartphone application. The experiment results show that the proposed group based scheme is suitable for information sharing over vehicles and pedestrians.

## The concept and challenges of Relay-by-SmartDevice

Relay-by-SmartDevice is riding on the strength of the popularization of mobile computing devices with high speed communication equipment. In addition to various vehicular embedded computers that are already deployed, smartphones and wearable computers such as wristbands and glasses are explosively growing in many places in the world. The widely distributed smart devices with various functionalities in our society and the revolution in computing and communication technologies allow us to communicate with neighbouring people directly or even in multihop fashion. It can be used as a communication method in the situations where the network infrastructure such as cellular systems and open access points of the Internet are not available, for example, disaster affected areas, islands, mountainous areas, and so forth. It can also be used for mobile traffic offloading [8] at the places where network infrastructure becomes overloaded such as shopping malls, music concerts, and conferences for the purpose of alleviating traffic congestion and reducing energy consumption.

In this article, we focus on network technologies that are necessary for Relay-by-SmartDevice. Major focused components are routing and storing technologies. In terms of routing, which is used to establish stable connections between devices, many researchers dedicated their efforts for distributed routing techniques for vehicular ad hoc network (VANET) [9] and mobile ad hoc network (MANET) [10], for decades. For example, Dynamic Source Routing (DSR) and Ad hoc On-demand Distance Vector (AODV) routing are notable traditional schemes [11]. Furthermore, regarding the store-and-forward techniques, which allow each device to store, copy, and carry information by using a storage, Delay Tolerant Network (DTN) [12] can be considered as a representative example.

Our first achievement in the study on Relay-by-SmartDevice is the development of the first ever experimental prototype of routing technology fusion, referred to as Relay-by-Smartphone, which effectively utilizes both MANET and DTN to construct the network of smartphones for message transmission using only their WiFi functionality in a multihop fashion [13]. According to the real-time mobility as well as the battery level, Relay-by-Smartphone allows devices to automatically switch between DTN and MANET modes for establishing stable connections with other smartphones. For instance, unmoving smartphones select the MANET mode which allow them to efficiently communicate with one another by constructing a large scale stable network, while moving smartphones carried by people select the DTN mode to enable direct Device-to-Device (D2D) communication between any pair of smartphones.

As demonstrated by the interconnection with Unmanned Aerial Vehicle (UAV)-based relay system [13] and Movable and Deployable ICT Resource Unit (MDRU) [14], the area in which messages can be exchanged by using Relay-by-Smartphone is able to be easily and extensively expanded. However, its performance in terms of efficiency of information dissemination is insufficient as a Relay-by-SmartDevice. This is because the routing technology adopted in Relay-by-Smartphone was specifically designated for walking people. In other words, the fusion of the two routing technologies, i.e., MANET and DTN, cannot fully function in the situations where vehicles and pedestrians coexist in the same field as potential users of applications provided by using Relay-by-SmartDevice technology.

Two of the most important and challenging characteristics of routing in Relay-by-SmartDevice are the mobility and the number of devices. When various devices contribute to the network for information sharing in a certain area, the difference between their mobility characteristics becomes larger as the number of kinds of devices increases. For example, vehicles and pedestrians have totally different mobility behaviors. Furthermore, the routing optimization becomes much more difficult as the total number of devices joining the routing procedure grows. Therefore, it is obvious that routing with vehicles and pedestrians is more complicated than that with only pedestrians, while it is expected that the collaborative routing of vehicles and pedestrians results in the dramatic performance improvement of Relay-by-SmartDevice in terms of information sharing efficiency.

The challenges in Relay-by-SmartDevice with numerous vehicles and pedestrians have motivated us to focus on effectively forming the groups of devices to deal with the large number of relay devices while considering their mobility. By allowing neighbouring devices to locally form a group in a distributed manner, routing control overhead can be mitigated, and it becomes easier to keep connections stable in each group by appropriately adjusting the size of the group. While information sharing is limited within each group during a very short period of time, it can be propagated outward by repeatedly disbanding and forming groups according to the dynamically changing situations. In other words, our motivation is to answer the questions: How to decide the size of a group? How to select a group leader? How to disband existing groups and form new groups? The technology to answer each question needs to be well designed in order to maximize the efficiency of information sharing among devices, i.e., the moving vehicles and pedestrians in this article.

Figure 2 shows an example of the envisioned process. At first, there are two groups in the area, namely A1 and A2. The members in each group have different messages. After the moment when some group members suddenly move, the previous groups cannot be maintained. Groups A1 and A2 will be disbanded and the three new groups, B1, B2, and B3 will be formed to keep more stable connections between group members. Furthermore, by doing this, the members in group B2 can have both messages previously held in A1 and A2. It is because some members still keep the old messages in the storage and can share the messages with the members in the new group. If we continue doing this process, C1, C2, and C3 can be created where all members receive both messages. In this manner, the envisioned process can be used to disseminate the messages among the devices.

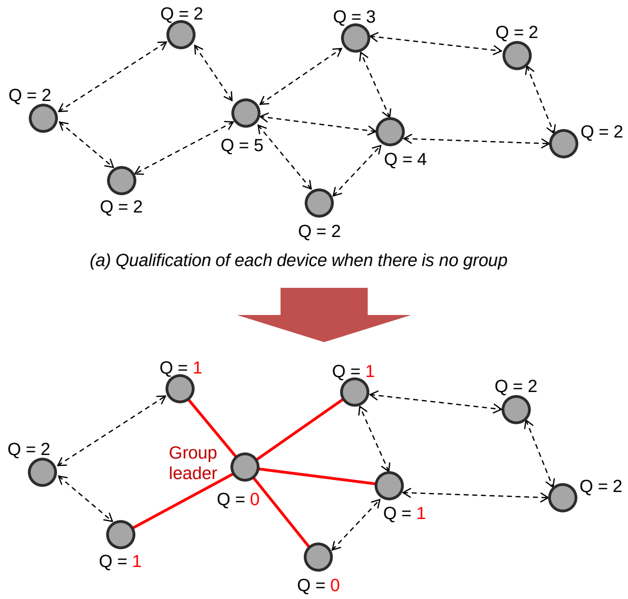
## A group based information sharing

In this section, we propose an intermittent group based information sharing technology for mobile communication devices, which are expected to be held by pedestrians or mounted on vehicles. All members belonging to the same group can communicate to each other through stable wireless links while they cannot communicate with non-members outside the group at all. Our proposal includes two procedures for group forming and group disbanding, which are based on three criteria, namely the Stability of the group, the Activity of the group, and the Qualification as a group leader.

### *Criteria of grouping*

The first criterion is the Stability of a group. In other words, a group must be formed so as to satisfy the requirement of guaranteeing the stability of the group. How to quantify the stability of the group is still an open issue. For example, geographical distribution of members, variance in relative velocities of members, Signal-to-Interference Noise Ratio (SINR) or Bit Error Rate (BER) observed at each member, packet probing examination results obtained between any pair of members, etc., can be considered. It is noted that, in general, the stability of a group tends to become lower when the number of members, i.e., the group size, increases.

The second criterion is the Activity of a group, which indicates the degree of activity in terms of information exchanges among members. Since information exchange is only allowed within each group, information will never be disseminated outward until we disband the group and form a new one by changing members. However, it is inefficient to disband a group during the period of time when members are about to exchange a lot of information with each other, which may disconnect ongoing data transmission and significantly increase unnecessary control overhead for group management. Thus, the Activity of a group is used for determining the appropriate timing of executing a group disbanding. In other words, a group is maintained during the time when the Activity is high. Counting the amount of information




*(a) Qualification of each device when there is no group*

*(b)* Qualification *of each device after formation of a group*

***Figure 3*** *Example of calculating Qualification, Q.*

exchanged in a group per unit of time is a simple example of an implementation method of the Activity. As another example, the Activity can be the number of group members desiring to receive information if we consider the amount of information being exchanged in the group in the future. It is effective even in the unexpected case that the connectivity of a group deteriorates from time to time due to the disconnection of some members in the group. On the other hand, excessive forming and disbanding causes unnecessary energy consumption and a short battery life. Thus, waiting for the disbanding of groups for a scheduled time is a reasonable method to reduce energy consumption even if no members have information to be disseminated. Note that a periodical and/or a time-synchronized group disbanding procedure can be used instead of the Activity driven scheme according to the purpose of information dissemination applications and services.

The last criterion is the Qualification as a group leader. In our proposed technique, a group forming procedure starts from the competition to be a group leader, which is conducted based on their Qualifications, and the group is expanded from the selected leader with the satisfaction of the Stability of group. Therefore, the formulation of Qualification as a group leader can be designed based on the geographical distribution of competitors and/or the amount of information to be disseminated, so as to contribute to reliable and efficient information disseminations. Relative velocity of competitors is also important in our research to establish stable connection, which has been the main objective in many studies in literature, especially the ones in vehicular ad hoc networks [15]. Another significant factor to be considered in the calculation of the Qualification is the remaining battery level as used in the mode selection procedure in Relay-by-Smartphone. In Relay-by-Smartphone, a node with low battery level selects the DTN mode for energy saving, because the MANET mode consumes more energy than DTN mode due to route maintenance procedures. In the same manner, the Qualification should be set to a small value in low energy nodes so that those nodes are not selected as a group

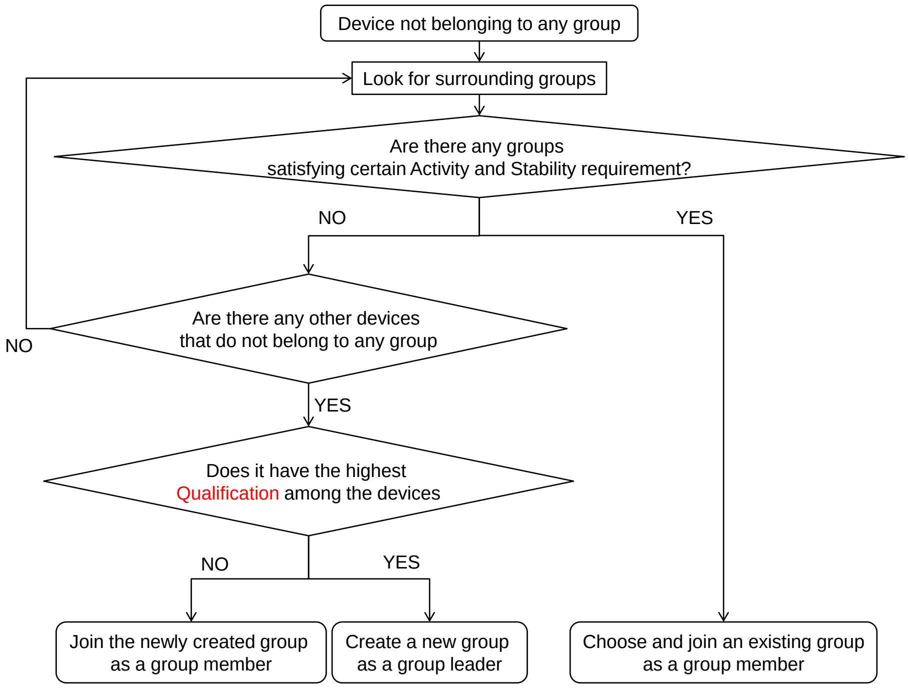



***Figure 4*** *Flow chart for forming a group.*

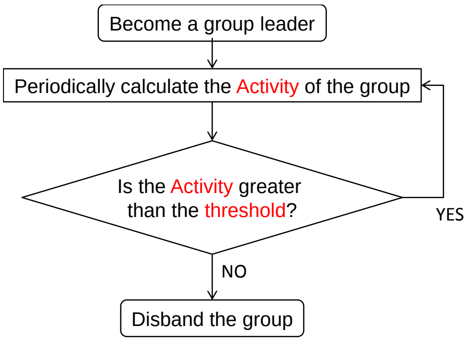



***Figure 5*** *Flow chart for disbanding a group.*

leader, since a group leader consumes more energy for executing group management procedures.

As mentioned above, the manner to calculate these three metrics can be different in implementation due to hardware limitations, e.g., with or without a Global Positioning System (GPS) module. Furthermore, it may dynamically switch between multiple calculation methods depending on application types, usage scenarios, and so forth.

Note that our grouping technology is independent from routing technique utilized to accomplish data transmission for information sharing in each group.

## *Group forming*

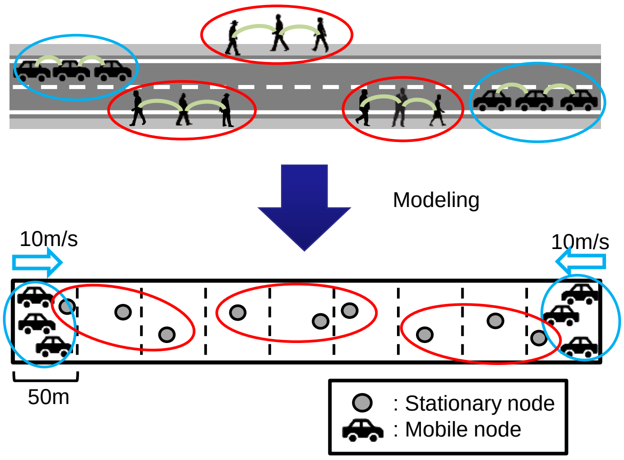
Closely located non-grouped devices cooperatively try to form a group by starting the group leader selection procedure using their Qualifications. After that, the selected group leader begins to recruit group members around it, and expands the group size by satisfying the Stability of the group.

An example of group leader competition is shown in Figure 3. Figure 3a shows the situation where there is no group. Here, the Qualification Value, Q, of each device is calculated as the number of devices that are inside its communication range. However, when there already exist groups, as in Figure 3b, Q is the number of devices inside the communication range that do not belong to the same group. The devices belonging to the same group are excluded to avoid the group leader being the same device every time. After all devices finish calculating their values of Q, the device having the highest value of Q will become the group leader, and all other devices will join the group as members. Once the new group is organized, the Qualification Value of each group member is updated. We can see that, by comparing two pictures in Figure 3, after a new group was formed (demonstrated by using red links), the value of Q of the members in the group decrease. This is to encourage information dissemination by mitigating the concern that an exactly same group will be formed just after a group is disbanded.

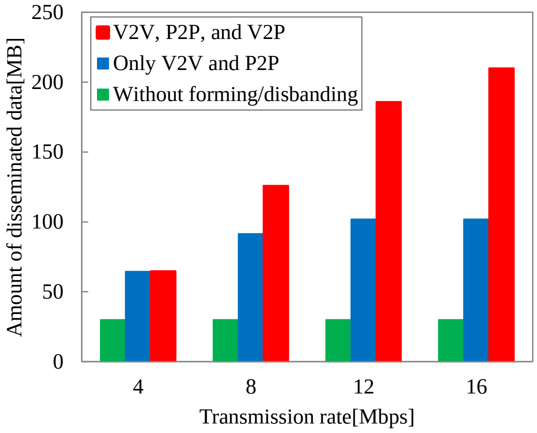
Figure 4 illustrates the flow chart of the procedure for forming a group and selecting a group leader. As shown in the figure, a device that does not belong to any group will first look for any available group surrounding it. If there are some groups satisfying certain Activity and Stability requirements, it will choose and join one of them. If there is no available group in the surrounding area, it will look for other devices that do not belong to any group to form a new group with them. A group leader of the new group will be the device with the highest Qualification.

## *Group disbanding*

The flow chart of the procedure for disbanding a group in our proposed scheme is illustrated in Figure 5. This process is carried out by the group leader who periodically calculates the Activity of the group. Whenever the Activity of the group is less than a given threshold, the group will disband. After that, the members of that group will start the process of forming a new group.




*(a) Considered scenario*




*(b) Numerical results*

***Figure 6*** *Evaluation of the proposed group forming and disbanding processes.*

### *Effect of group forming and disbanding*

Here, we evaluate the information sharing effectivity of three methods of group forming and disbanding. Numerical analyses are conducted using the model shown in Figure 6a. In this model, the considered network consists of vehicles and pedestrians. Six mobile nodes and nine stationary nodes represent vehicles and pedestrians, respectively. To simplify which pair of nodes is near enough to communicate with each other, the road is separated into nine cells, which are 50m wide. This is reasonable to consider the distance for calculating the Stability of a group. For example, there can be a setting where, in order to keep the Stability, the distance between any pair of nodes in a group must to be less than 150m, which equals the total width of three adjacent cells. At the initial state, the groups are formed as shown in Figure 6a and each node has 1MB of data to disseminate to others. Mobile nodes move to the opposite side with the speed of 10m/s, which means that they stay in each cell for five seconds and take 45 seconds to finish covering the road of our model.

We present three methods for comparison. The first method is “Without group forming/disbanding”, which means that a group maintains the connections made in the initial state. The second method is “Group forming/disbanding only for V2V and P2P”, which means that stationary nodes or mobile nodes cannot form a group with each other. The last method is “Group forming/disbanding for V2V, P2P, and V2P”, which means that stationary nodes and mobile nodes form groups with each other seamlessly. Furthermore, we explain the definition of the three criteria in our analyses. We define the Stability by the requirement that the distance between any pair of group members must be less than the total width of three cells. Regarding the Activity of the groups, we synchronize the time intervals of five seconds to let the groups disband and join at the same time. Then, we assume that the Qualification to be a group leader depends on the number of devices that are inside its communication range but not belonging to the same group. We define the communication range of a device as three cells, which are the cell where the device exists and the adjacent cells on both sides.

In our analyses, we calculate the “amount of disseminated data” during the 45 seconds, which is the time the mobile nodes take to finish covering the road of our model. We use time division, which makes the time consisting of divided time slots. We define the “amount of disseminated data” as the sum of the amount of transmitted data in each time slot. In each time slot, the amount of transmitted data in each group is limited by a certain transmission rate. For example, in a time slot, a node of each group transmits certain volume of data, which is calculated by the transmission rate to another member. Our analyses are conducted at the transmission rates of 4, 8, 12 and 16Mbps. However, in these analyses, V2V and P2P communications can overlap each other in a cell. Considering the interference in this case, the transmission rate of a group is reduced by half when, within the three cells covered by that group, there exists a group leader of another group.

The numerical results are shown in Figure 6b. In the method “Without group forming/disbanding”, the amount of disseminated data is constant at a low level. In the “Group forming/disbanding only for V2V and P2P”, the amount of disseminated data is limited by an upper bound at the transmission rates of 12 and 16Mbps. On the other hand, in the “Group forming/disbanding for V2V, P2P, and V2P”, we attain the highest amount of data dissemination at all transmission rates. This result caused by the difference of the number of nodes which each node can communicate with. In these analyses, each node initially has 1MB data to disseminate to others. In the case the transmission rate is high enough to disseminate data, the 1MB data will be transmitted to all nodes which the node can communicate with directly or indirectly. For example, in the method “Without group forming/disbanding”, the 1MB data will be transmitted to the other two member nodes of the initial group. Additionally in the “Group forming/disbanding only for V2V and P2P”, the data which is initially possessed by each mobile or stationary node will be transmitted to the other five mobile nodes or eight stationary nodes, respectively. In the “Group forming/disbanding for V2V, P2P, and V2P” at the transmission rate of 16Mbps, the amount of shared data achieves 210MB, which indicates that all data are disseminated to all devices within the model. Therefore, in these analyses, we see that group forming

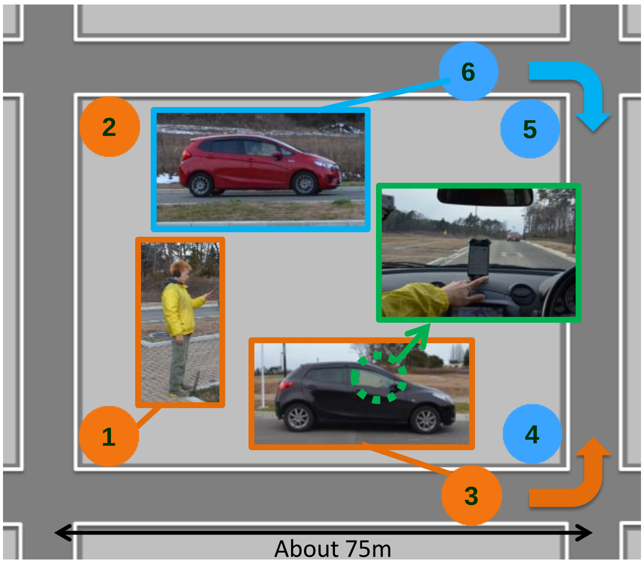



***Figure 7*** *Scenario of the field experiment using the prototype.*

with V2P communication can contribute to improvement of information sharing effectivity.

## Prototyping and field experiment

We have implemented a prototype of Relay-by-SmartDevice technology as a smartphone application, called the second generation of Relay-by-Smartphone, so that it can be used for P2P communications and also can be put inside cars for demonstrating V2P and V2V communications. The field experiment using the prototype was conducted in Aobayama campus of Tohoku University in Sendai city, in December 2014.

### *Prototype of Relay-by-SmartDevice: the second generation of Relay-by-Smartphone with WiFi Direct*

Since the major objective of this prototype is to verify the information dissemination by repeatedly forming and disbanding groups, group size adjusting function is not implemented. In other words, the prototype utilizes WiFi Direct functionality in order to form a group, and thus a group member is directly connected to a group leader with one-hop. The Activity is checked periodically with a time out setting. For example, if the time out setting is 30 seconds and there is no transmission between the group members in 30 seconds, the group will be disbanded. The use of WiFi Direct contributes to simplifying the implementation of the group forming procedure since it provides a group leader selection function based on the Qualification Value, which is calculated as shown in Figure 3. In our prototype, the Qualification to be a group leader is calculated from the Qualification Value, and the value can be set manually or automatically depending on the aim of each experiment.

### *Performance verification in the field*

The experiment was carried out with two cars and four people each carrying a smartphone installed with the prototype. Figure 7 illustrates the scenario of the experiment. In a rectangle course, four people (elements 1, 2, 4, and 5) remained stationary and two cars (elements 3 and 6) moved around in opposite direction to each other. At first, two groups were formed. Group A consisted of element 1, 2, and 3 while group B had element 4, 5, and 6. After element 1 sent out a message to all other members of its group, i.e., element 2 and 3, the group had no further communications until time out. Therefore, group A was disbanded. After that, element 3 joined group B, resulting in group B consisting of elements 3, 4, 5, and 6. Right after joining group B, element 3 could disseminate the message received from element 1 before. The total time necessary for element 3 from disbanding group A until successfully sending the message to all members of group B was 24 seconds.

The experiment successfully confirmed the implemented prototype with the concept of Relay-by-SmartDevice. Although the scale of the experiment is small, it was enough to confirm that the prototype can work with the normal car speed. Thus, it shows the potential to utilize the proposed technology in communications among vehicles and pedestrians.

## Conclusion

In this article, we proposed a concept of Relay-by-SmartDevice for realizing efficient information sharing among mobile communication devices, especially for devices carried by vehicles or pedestrians. We proposed a mechanism for forming and disbanding the groups of vehicles and pedestrians depending on network situations. Three criteria, i.e., the Stability of the group, the Activity of the group, and the Qualification to be a group leader, were introduced. We also proposed procedures for forming and disbanding functions. Furthermore, we implemented a smartphone-type prototype, referred to as the second generation of Relay-by-Smartphone, with the use of WiFi functionality. The experiment results demonstrated that the proposed group based information sharing technology is a good candidate for use in V2P, V2V, and P2P communications.

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