Bachelor's Thesis

Academic Year 2010

iDANS: A Location Based Information Dissemination Platform for In-vehicle Smartphones in VANETs

Faculty of Environment and Information Studies
Keio University

Dan Sawada

Abstract of Bachelor's Thesis

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iDANS: A Location Based Information Dissemination Platform for In-vehicle Smartphones in VANETs

In this thesis, a platform called iDANS, which enables location based information to be disseminated among smartphones in vehicular ad-hoc networks (VANETs), is proposed, implemented and evaluated.

Along with the advancement of mobile networks, the technologies to generate and share location specific information through inter-vehicular networks have been developed. In this research, smartphones will be focused as in-vehicle communication devices. Also, an efficient method to disseminate location specific information on VANETs consisted of smartphone nodes will be discussed.

The primary objective of iDANS would be to disseminate and share location specific information swiftly among vehicles within a designated area where it is most useful for the drivers. In order to meet the demands, iDANS disseminates the information most relevant to the current location on a priority basis. It also makes use of devices that cannot acquire the current location accurately as relay nodes.

As a result of operation tests and simulations, it has been verified that iDANS is effective in disseminating information swiftly among the vehicles within a designated area.

Keywords :

1. Vehicular Ad-Hoc Networks, 2. Information Dissemination, 3. Current Location, 4. Smartphones

Faculty of Environment and Information Studies, Keio University

Dan Sawada

卒業論文　要旨

平成 22 年度

iDANS: スマートフォンを用いた車両間アドホックネットワークにおける位置情報に即した情報流布基盤

本研究では, 車載が容易なスマートフォンを用いて構築された, 車両間アドホックネットワークにおいて, 位置情報に即した情報の流布を行うプラットフォームである「iDANS」を構築し, 評価を行った.

近年, モバイル通信技術が発展する中で, 車両間ネットワーク上で「空間上の場所」に関する様々な情報を生成し, 共有する技術の研究開発が多方面で進められている．そんな中, 車載が容易なスマートフォンを用いて構築されたアドホックネットワーク上で, 効率良く情報を流布する手法について検討した.

渋滞情報など, 運転中に役立つ情報の多くは, 情報生成時から短時間のうちに, その情報が最も有用となる場所を走行中の車両に対して流布されることが望まれる．そこで, iDANS は特定エリア内の車両同士で, 迅速かつ多くの情報を共有することを目的とした. 目的を達成するために, iDANS は走行中の場所に応じて, 最も流布すべき情報を優先的に流布する機構を備えた．また, 位置情報を正確に取得出来ない端末を中継ノードとして有効利用することも可能とした.

iPhone を用いた実機動作検証とシミュレーションによる効果測定の結果, iDANS は特定エリア内の車両間で多くの情報を迅速に流布する上で有効であることを確認できた.

キーワード:

1. 車両間アドホックネットワーク, 2. 情報流布, 3. 現在地, 4. スマートフォン

慶應義塾大学　環境情報学部

澤田　暖

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Chapter 1

Introduction

This chapter describes the background and the purpose of this research. It also elucidates the composition of the entire thesis.

1.1 Background

This section explains the background of this research, from the informatization of vehicles to the evolution of smartphones and related portable devices.

1.1.1 Informatization of Vehicles

Vehicles have been one of the most important methods of mobility to us human beings. They have gone through several innovations since they were first introduced, and today, vehicles are starting to become part of the internet.

Among the numerous researches and developments based on the internet connected vehicles, the Probe Vehicle System[1] would be one of the typical examples. The Probe Vehicle System is a system in which the vehicles are regarded as probes that sense the real world. The key idea is to collect the sensor data from vehicles on the streets via the cellular IP network, and generate various types of useful information. For example, by gathering the velocity data along with location coordinates, it is possible to generate accurate traffic information. Also, the gathering of wiper status data enables the generation of pinpoint precipitation information. Figure 1.1 shows an example of the precipitation information generated by the wiper status data from vehicles[1].

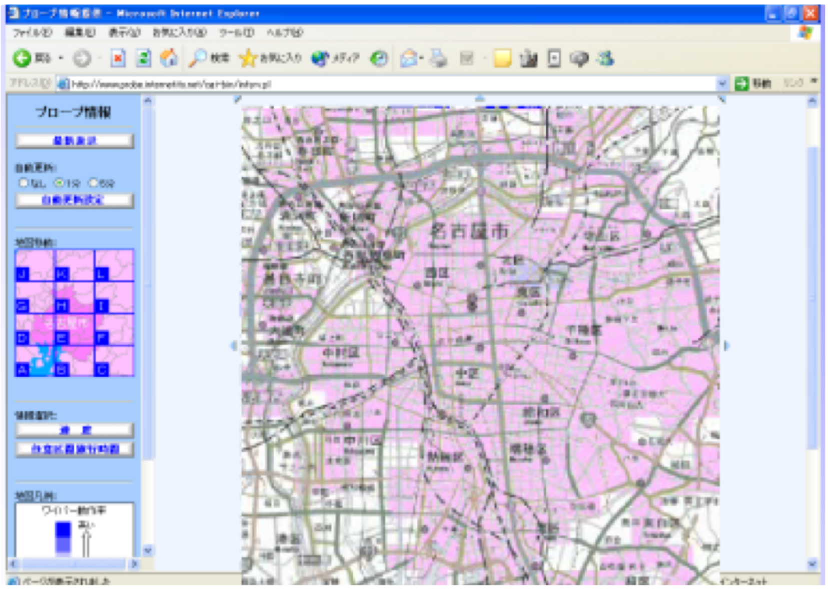

Figure 1.1 Precipitation Information Generated by the Wiper Status

Currently, equivalent systems are operating as commercial services by major automobile manufacturers. Such services include Toyota's G-BOOK[2], Nissan's Carwings[3] and Honda's Internavi Premium Club[4]. However, as a major issue, these systems completely rely on the existing infrastructures in terms of communication and service provision.

Meanwhile, there are researches based on vehicular ad-hoc networks (VANETs), where vehicles communicate directly with each other without using the existing communication infrastructures. Instead, they use short range communication interfaces such as Wi-Fi[5], which is based on IEEE 802.11 wireless LAN standards. Figure 1.2 shows an example where vehicles generate and share traffic information with each other using ad-hoc communications.

By using ad-hoc communications, vehicles will be able to interact and share information with each other in a decentralized form, without relying on the existing mobile

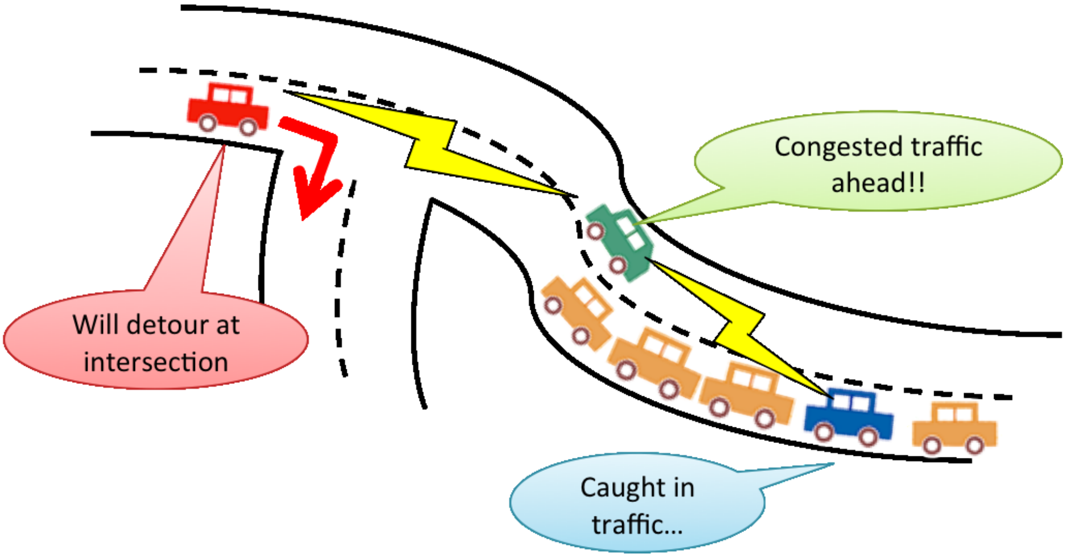

Figure 1.2 Model of the Decentralized Probe Vehicle System

communication infrastructures or service providers. When these types of systems are widely spread throughout vehicles on the streets, it is likely that driving experiences will improve, since the drivers will be able to seamlessly acquire various types of information, whether or not conventional communication methods are available. However, as a trade off, a high initial deployment level of nodes would be required for the efficient operation.

1.1.2 Emerging of Smartphones and Related Devices

On the other hand, portable gadgets such as smartphones and tablet devices are rapidly developing and drawing public attention. According to the 2009 Survey Result on Smart Phone Markets[6], a total of approximately 137 million smartphones were shipped out worldwide in 2008. This number is expected to double by 2012.

Today, there are numerous types of portable devices on the market that may be used inside vehicles. Such include portable navigation devices (PND), multimedia players, and many more. Compared to those portable devices, smartphones have the following key features.

- Multiple network interfaces (i.e. 3G, Wi-Fi, and etc.) for communication
- Various sensors (i.e. accelerometers, GPS sensors, cameras, and etc.) for acquiring the context
- A sophisticated user interface (i.e. touch panels) enabling easy usage
- A relatively open environment for application development

Since smartphones are originally used as cellular phones, it will be easy for drivers to bring them into their vehicles as shown in Figure 1.3. Thus, VANETs consisted of smartphone nodes may easily be deployed in the initial stage, without the need of specialized equipments.

Figure 1.3 In-vehicle Smartphone

1.2 Purpose

With the background described in Section 1.1, the purpose of this research is to develop a platform called iDANS[*1], which enables in-vehicle smartphones to exchange various types of location specific information in an ad-hoc configuration. Upon exchanging information, an efficient dissemination method would be necessary, since the connections in VANETs are very limited in terms of the bandwidth and the communication time frame. Therefore, this thesis will mainly focus on the dissemination methods among smartphones in VANETs.

1.3 Structure of the Thesis

Chapter 2 will introduce the existing researches related to the information dissemination in VANETs. Based on the considerations of existing methods, the design approach of iDANS will be discussed.

Before drawing up the details of the design, preliminary experiments were required to reveal the issues of actual in-vehicle smartphone nodes. The details and results of the preliminary experiment will be discussed in Chapter 3.

Given the results of the preliminary experiment, the specific design of iDANS will be proposed in Chapter4. The implementation of iDANS will be discussed in Chapter 5.

In order to evaluate the proposed platform, iDANS, operation tests and simulations were conducted. The details and results of the conducted tests and simulations will be discussed in Chapter 6. Based on the evaluations, the outcomes of this research will be stated in Chapter 7, along with the issues that remains to be solved in the future.

[*1] iDANS: Information Dissemination on Ad-hoc Networked Smartphones

Chapter 2

Information Dissemination in VANETs

Since vehicles constantly move, the connections between nodes in VANETs are very limited in terms of the bandwidth and the communication time frame. Therefore, an efficient information dissemination method will be necessary in order to make the most out of the limited connections.

This chapter introduces the existing researches regarding information dissemination in VANETs. It also discusses the approach to designing iDANS, which is an ad-hoc information dissemination platform for in-vehicle smartphones.

2.1 Related Researches

This section introduces the basic facts of existing researches related to the information dissemination in VANETs.

2.1.1 SOTIS

The Segment-oriented Traffic Information System (SOTIS)[7] is a system that enables vehicles to generate and share traffic information related to a particular road segment in VANETs.

When generating traffic information, vehicles would first broadcast its knowledge about the traffic situation to other vehicles within its transmission range. If a piece of information is received from other vehicles, it will be evaluated and stored in the node. Based on this analysis, a traffic profile of the surrounding area will be generated and disseminated to others.

The effectiveness of the SOTIS was evaluated based on the simulation results. In the simulation, the traffic information was created and disseminated among vehicles travelling along a highway. As a result, SOTIS demonstrated that it was possible to generate and share traffic information with high details over a large area in the range of 25 to 50 kilometers.

2.1.2 RMDP

The Received Message Dependant Protocol (RMDP)[8] is a protocol for disseminating and propagating the preceding traffic information to the surrounding vehicles.

The basic idea of RMDP is to dynamically change the dissemination interval depending on the number of reception messages for avoiding packet collisions. The fewer messages the node receives during the given time frame, the shorter the interval will become for disseminating the information.

The efficiency in reducing the packet collisions was measured and evaluated on the simulators that replicate the mobility of vehicles in urban environments. From the results, RMDP was successful in maintaining low packet collisions rates under congested environments. It was also effective in terms of reducing packet collisions when the radio transmission range of nodes was increased.

2.1.3 Decentralized Probe Vehicle System

The Decentralized Probe Vehicle System[9] is also a system that enables vehicles to generate and share traffic information.

The basic generation process of traffic information of the Decentralized Probe Vehicle System is similar to that of SOTIS, except that it appends the information with a dissemination target in geographical coordinates, and a radius in distance indicating the area where the information would be the most demanded.

When disseminating the information, nodes will first calculate the distance between the dissemination target and the current location for each piece of information. If the distance is within the radius, it will be put on broadcast queue. If not, it will not be transmitted. The information within the queue will be broadcast on a priority basis, depending on the distance from the dissemination target. This mechanism enables the information to be shared rapidly and efficiently among vehicles within a certain area.

The Decentralized Probe Vehicle System also enables the directional dissemination[10] as shown in Figure 2.1. When a new piece of information is generated in a vehicle, it will first be disseminated in the convergence mode toward the dissemination target, so that it may be integrated with other relevant information to form a decent profile indicating the traffic situation. After a decent profile is created, it will be disseminated toward the rim of the dissemination area in the diffusion mode, to notify the traffic conditions to the nodes heading for the dissemination target.

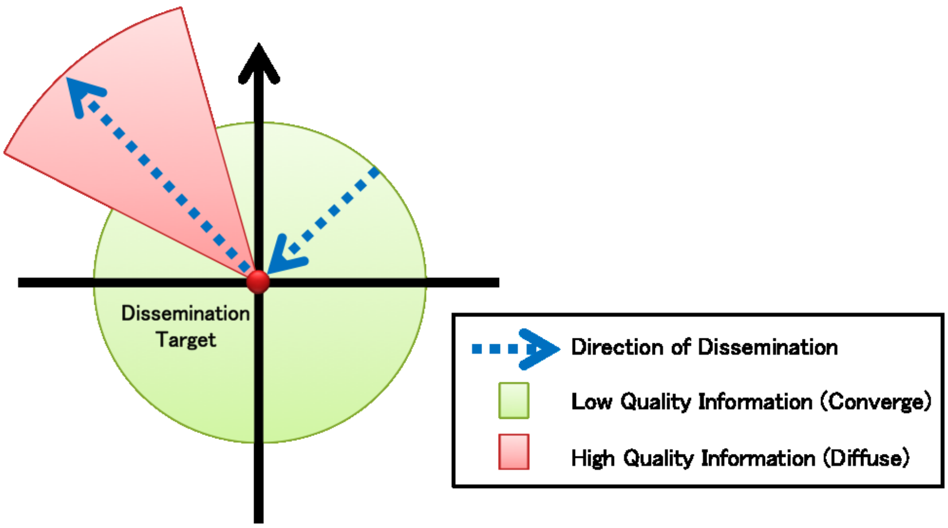

Figure 2.1 The Direction of Information Dissemination

From the results of verification tests using actual vehicles, the Decentralized Probe

Vehicle System was successful in generating the traffic congestion information. Also, the simulations demonstrated that the directional dissemination model of this system was more time efficient than the random transmission model, when generating traffic information.

2.1.4 PeerTIS

The PeerTIS[11] is a peer-to-peer overlay network architecture, optimized for generating traffic information among vehicles in a decentralized form.

The capacities of conventional VANETs are very limited, and must face high latencies when disseminating data, since the network topology and connection statuses will change constantly as the vehicles move.

The PeerTIS makes an approach to solve these issues by structuring a peer-to-peer overlay network of vehicles. The proposed network architecture enables data to be disseminated beteween vehicles in a decentralized form, without relying on the conventional ad-hoc network. In order to improve the lookup performance, balance the load distribution, and reduce the bandwidth usage, the conventional overlay structure based on the Content Addressable Network (CAN)[12] was tailored to the specific properties listed below.

- Spatial and temporal correlations between the user's actions
- Topological dependencies among the data stored in a node
- Awareness of the current user position

The effectiveness of the PeerTIS was evaluated by using a simulator. From the results, PeerTIS was proven to reduce the usage of bandwidth and the number of hops per lookup among vehicles compared to the original CAN architecture.

2.2 Approach to Designing iDANS

Information indicating traffic congestions and slippery points will be the most effective when spread rapidly among vehicles near the site of occurrence. Therefore, iDANS will figure out a method for disseminating information rapid within a designated area.

The dissemination methods of RMDP indicated in Subsection 2.1.2 may be effective in reducing the packet collisions. However, the information will not be weighted based on any of the characteristics, including the location, upon transmission. Thus, the dissemination method of RMDP may be inadequate in terms of disseminating the information within the designated area with efficiency.

Since the methods of SOTIS binds all the information to road segments, it will not be able to handle and disseminate the information irrelevant to a particular road segment. Considering the dissemination of various types of location specific information, the information dissemination methods of SOTIS indicated in Subsection 2.1.1 may not be suitable.

The peer-to-peer overlay architecture of PeerTIS indicated in Subsection 2.1.4 is relatively a new approach to disseminating information in a decentralized form among vehicles. Since PeerTIS relies on the 3G cellular networks as a foundation, it may seem feasible to smartphones. However, it also means that PeerTIS cannot be deployed in places where high quality 3G cellular networks are not available. The deployment of PeerTIS in the definitive urban areas of developed countries may not be a problem. But considering the dissemination of information among vehicles in rural areas and developing countries, this architecture of PeerTIS still remains inadequate.

The information dissemination platform of the Decentralized Probe Vehicle System indicated in Subsection 2.1.3 selects the information to transmit based on the current location. This mechanism enables the rapid and efficient dissemination of information within a particular area. Therefore, it would best fit the needs of this research in terms of disseminating various types of location specific information, seamlessly and rapidly among vehicles in the designated area.

Based on these facts, iDANS would be designed based on the information dissemination methods of the Decentralized Probe Vehicle System[10]. However, the given dissemination algorithm is not intended to be used by smartphones nodes. Thus, the capabilities and issues of in-vehicle smartphones must be revealed before details of the platform are designed.

Chapter 3

Issues of In-vehicle Smartphones

As discussed in Section 2.2, iDANS would be designed based on the dissemination algorithm proposed in the Decentralized Probe Vehicle System[10]. Before details of the platform were designed, the capabilities and issues of smartphones in vehicular environments had to be revealed, since the base algorithm had not been intended for use on smartphone nodes.

This chapter discusses the details and results of the preliminary experiment, which was conducted to reveal the capabilities and issues of smartphones in vehicular environments.

3.1 Experiment Overview

In the experiment, the capabilities of in-vehicle smartphones in ad-hoc mode were examined from the following aspects.

- Packet loss rate between two devices by the distance and device context
- Throughput between two devices by distance
- Accuracy of the location sensor by vehicle status

3.2 Experiment Equipment

This section explains the equipments used in the experiment.

3.2.1 In-vehicle Devices

In this experiment, an iPhone 3GS[13], an iPhone 4[14], and an iPad (Wi-Fi + 3G model)[15] were used as in-vehicle devices, and Wi-Fi was used as network interfaces. Table 3.1 indicates the basic specifications of these devices.

Table 3.1 Basic Hardware Specifications of Devices Used in Experiment

	iPhone 3GS	**iPhone 4**	**iPad**
CPU	Cortex-A8 600 MHz	Apple A4 1 GHz	Apple A4 1 GHz
Memory	256 MB	512 MB	256 MB
Wi-Fi	IEEE 802.11b/g	IEEE 802.11b/g/n	IEEE 802.11b/g/n
Location Sensor	Assisted GPS	Assisted GPS	Assisted GPS

For acquiring the location coordinates, iPhones and iPads uses Assisted GPS[16]. This is a GPS based location sensor assisted by cellular and Wi-Fi signals. It will correct and adjust the sensor data acquired by the GPS receiver with the strength of signals from cellular base stations and Wi-Fi access points.

3.2.2 Ad-hoc Networks on iOS

As of December 2010, iOS (operating system for iPhones and iPads) doesn't officially support the creation of ad-hoc networks using Wi-Fi. However they are eligible to join into existing ad-hoc networks created by other devices such as laptop computers. The ad-hoc network configurations will remain active even after the original creator of the network is shut down, as long as the device is awake and does not go into sleep mode.

Based on these facts, the ad-hoc network was built with iPhones and iPads by the following procedures.

1. Create an ad-hoc network using Wi-Fi on MacBook Pro with Mac OS X 10.6.
2. Join iPhones and iPads to the created network.
3. Shut down the Wi-Fi on the MacBook Pro.
4. Disable the sleep function on iPhones and iPads to retain the network configurations.

3.3 Experiment Environment

This section discusses the environments and scenarios of the experiment.

3.3.1 Measurement of Packet Loss Rate

For measuring the packet loss rate, a measurement application was implemented on iOS. It will broadcast and receive UDP packets with the size of 1024 bytes, excluding headers. Each outgoing packet will be given a unique ID indicating the source and sequence number, in order to keep in track which packets were successfully delivered and which were lost. Also, when a packet is broadcast or received, the location coordinates of the node will be recorded on the log along with a time stamp. Figure 3.1 shows a screen dump of the application.

The measurement took place along the straight 630-meter-long road with a good view near Endo District of Fujisawa City, Japan, using two vehicles. One vehicle with an iPhone 4 was to drive back and forth along the road, and the other vehicle with an iPhone 3GS was to stay in a fixed position as indicated in Figure 3.2. The moving vehicle would send a packet to the static vehicle every second until it completes its 3 lap run around the course. The packet loss rate would be calculated by distance ranges of the two vehicles, from 0 to 250 meters with 50-meter increments in between.

The measurement was done under the conditions indicated in Table 3.2. The device

Figure 3.1 Screen Dump of the Packet Loss Measurement Application

context indicates where the device is placed within the vehicle; either it is mounted on the dashboard or it is placed on the passenger's seat as shown in Figure 3.3.

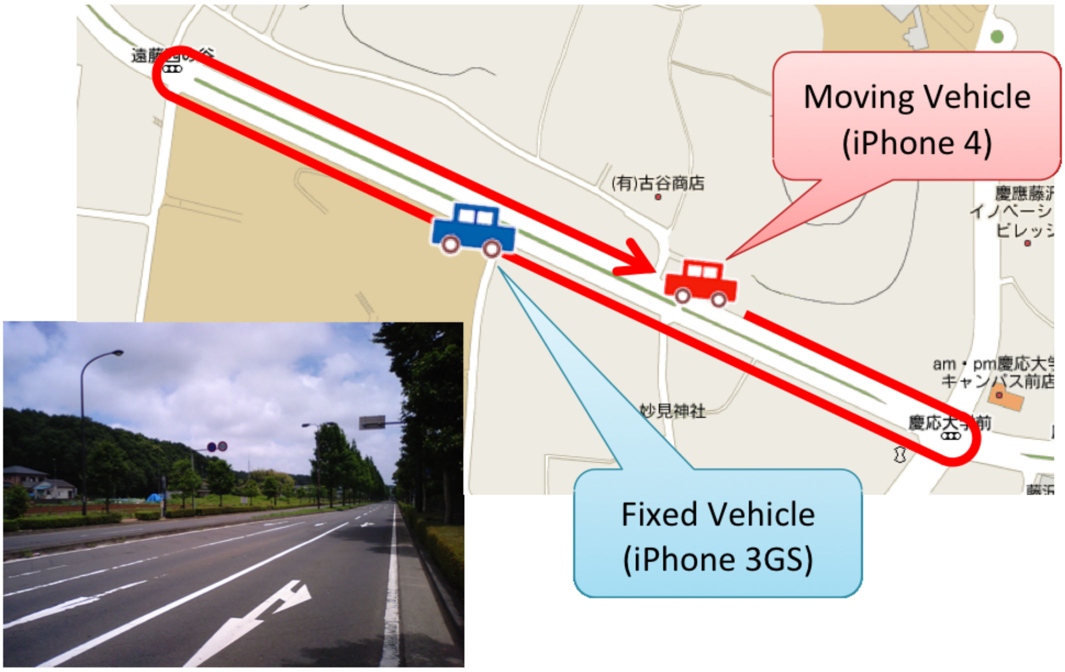

Figure 3.2 The Layout of Vehicles in Packet Loss Measurement

Table 3.2 Conditions of Packet Loss Measurement

Condition	**Device Context of Moving Vehicle**	**Device Context of Static Vehicle**
1	Dashboard	Dashboard
2	Dashboard	Passenger Seat
3	Passenger Seat	Passenger Seat

3.3.2 Measurement of Throughput

For measuring the bandwidth, an iOS application called WiFi Bench v.1.1.0[17] was used. WiFi Bench is a wireless network throughput tester that makes use of the iperf3 open source library to provide quick and accurate estimates of the wireless network performance.

In−vehicle Device
Mounted on Dashboard

In−vehicle Device
Placed on Passenger Seat

Figure 3.3 Context of In-vehicle Smartphones

As of December 2010, WiFi Bench only supports measurements using TCP. The actual throughput values may differ when UDP is used, but it will still provide an idea of how the distance between two in-vehicle nodes affects the throughput.

As it was with the measurement of packet loss rate, two vehicles, Vehicle A and Vehicle B were used. Table 3.3 indicates the detailed configurations. The bandwidth was measured by the distance of the two vehicles, which was increased by 50 meters until it reached 250 meters.

Table 3.3 Configurations of In-vehicle Devices in Throughput Measurement

	Vehicle A	**Vehicle B**
Device Model	iPhone 4	iPad
Device Context	Mounted on Dashboard	Mounted on Dashboard
iPerf Mode	Client	Server

3.3.3 Measurement of Location Sensor Accuracy

For measuring the location sensor accuracy, an iOS application that displays the latitude and the longitude acquired by the Assisted GPS sensor was implemented. In the measurement application, sensor values will be shown on the display every time the sensor acquires the new location coordinates.

To see the how the status of the vehicle would affect the accuracy, measurements were done in the following locations using a vehicle with an iPhone 4 mounted on its dashboard.

- An open air street without any obstacles (Endo District of Fujisawa City, Japan)
- A street running inside a tunnel that pierces a hill (Oba Tunnel of Fujisawa City, Japan)

The vehicle was parked at the points indicated in Figure 3.4, and the sensor was activated for 60 seconds to acquire the coordinates. The distance between the current location and the acquired points was measured to examine the accuracy.

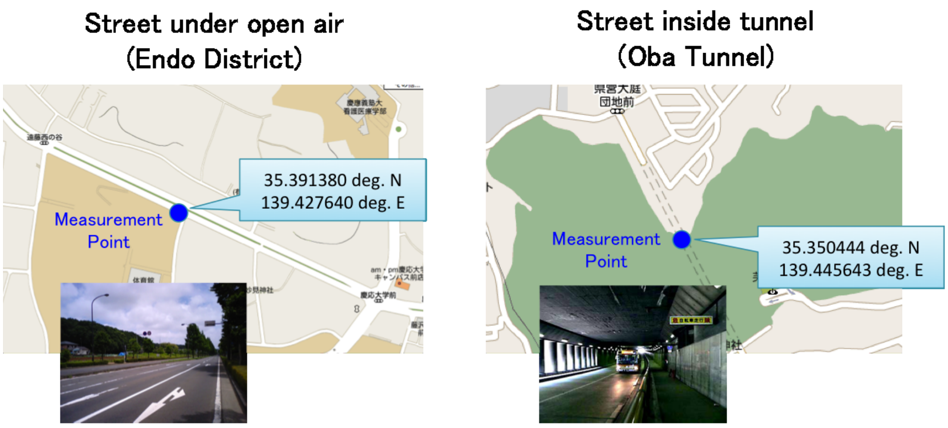

Figure 3.4 Measurement Points of the Location Sensor Accuracy

3.4 Results

This section reveals the results of the experiment.

3.4.1 Packet Loss Rate

Figure 3.5 indicates the results of the packet loss measurement. From the results, the packet loss rate increased as the two vehicles got farther away from each other. Also, when both devices were mounted on the dashboard, most packets were successfully received within a 100-meter radius. However, if one of the nodes were placed on the passenger seat, stable communication with a packet loss rate less than 10% was possible only within a 50-meter radius. Furthermore, when both devices were placed on the passenger seat, the packet loss rate rose to 16.5% in the 50-meter radius, and in distance ranges over 100 meters, barely any packets reached its destination.

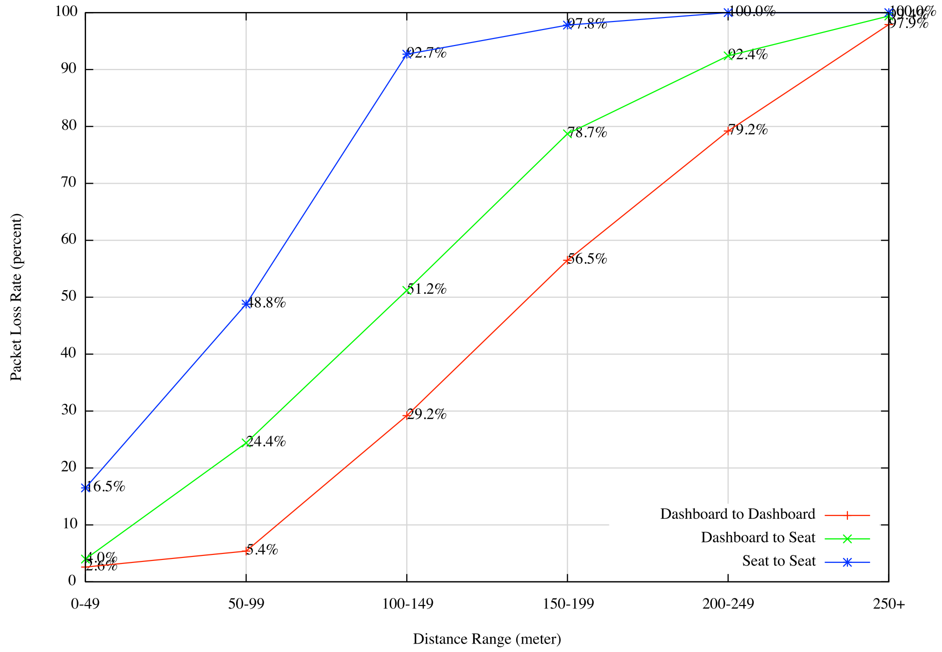

Figure 3.5 Packet Loss Rates by Distance Range and Device Context

3.4.2 Throughput

Figure 3.6 indicates the results of bandwidth measurement. The result indicates that the throughput between the iPhone 4 (client) and the iPad (server) was around 6.5 Mbps when the two were 50 meters apart from each other. The throughput continued to decline as the distance got longer, and at 250 meters, the throughput dropped to 0.2 Mbps.

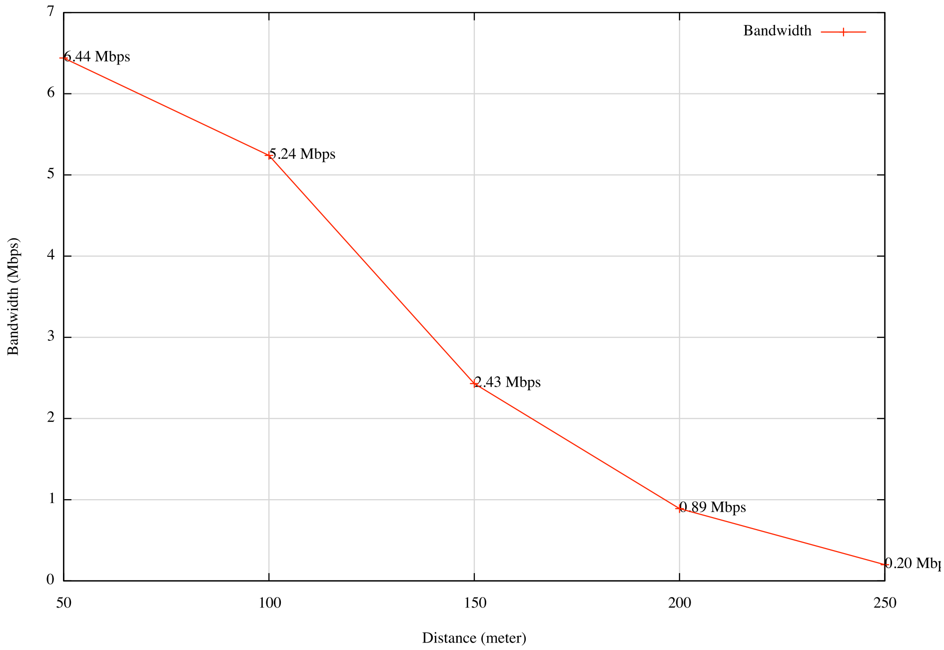

Figure 3.6 Throughput Between In-Vehicle Devices by Distance

3.4.3 Accuracy of the Location Sensor

Figure 3.7 indicates a map showing the points acquired by the location sensor. The measurement logs indicated two different sets of coordinates as the current position within the 60-second period. It turned out that the difference between the actual measurement point was within 11 meters when the vehicle was under open air. However, when the vehicle was inside a tunnel where normal GPS signals cannot be reached, the sensor pinpointed locations far too irrelevant, which were over 900 meters away at the most from the actual measurement point. It is presumed that these values were calculated based on the signals from cellular base stations.

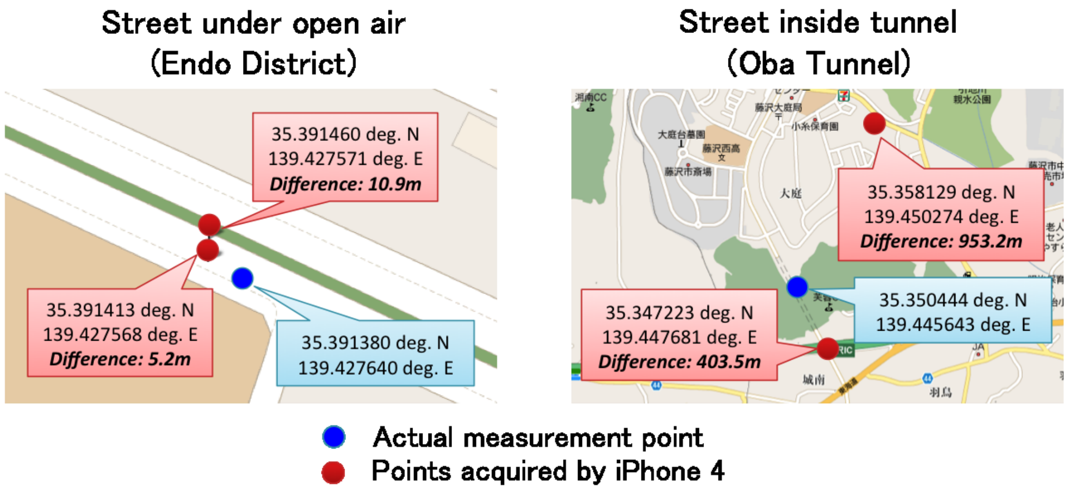

Figure 3.7 Points Acquired by the Location Sensor

These errors are rare when the current location of the vehicle is calculated by built-in navigation systems which combines sensors such as gyroscopes, electronic compasses, and speedometers with map data. These alternative methods adjust and correct values of the GPS when the signal is poor or nonexistent. Though Assisted GPS in iPhones and iPads is also eligible to obtain the current location using alternative method as discussed in Subsection 3.2.1, its capabilities are inadequate when compared to using native sensors embedded within the vehicle.

3.5 Considerations

From the experiment results, the following facts may be asserted as issues and capabilities of in-vehicle smartphones.

- The location sensors may return inaccurate location coordinates under certain situations, such as driving in places where GPS signals are poor.
- The device context of in-vehicle smartphones affect the quality of ad-hoc communication.
- In vehicle devices will still have the ability to communicate with each other, even if the quality of the location sensor is poor, or if the device is not placed in a perfect position for communication.

Chapter 4

Design

This chapter discusses the design of **iDANS**. The goal of iDANS would be to rapidly disseminate information among vehicles within a designated area. In order to meet the requirements, iDANS will be designed based on the information dissemination algorithm proposed in the Decentralized Probe Vehicle System[10].

4.1 Issues of In-vehicle Smartphones

Since the base algorithm is not intended to be used by smartphone nodes, preliminary experiments were done to reveal the capabilities and issues of in-vehicle smartphones. As a result, it was revealed that in-vehicle smartphones might return inaccurate coordinates under certain situations.

In the base algorithm, correct acquisitions of the current position are mandatory, since information would be disseminated based on the distance between the current location and the dissemination target. If information were to be generated by nodes with inaccurate location values, the information will be marked with inadequate dissemination targets, which may lead to efficiency losses.

Given these facts, in iDANS, information would be disseminated according to the current location when nodes can acquire the current location accurately. On the other hand, nodes that cannot acquire the accurate location positions would be used as relay nodes, which retransmits the information received.

4.2 Dissemination Methods

In iDANS, information will be disseminated through two different methods; the **Location Based Dissemination** which is intended for smartphone node with accurate locations, and the **Reception Based Dissemination** intended for nodes with inaccurate locations.

4.2.1 Location Based Dissemination

The **Location Based Dissemination** will enable information to be disseminated within a circular range specified by the following parameters. The parameters are to be configured by each individual application based on the intended purpose.

- **Dissemination target** expressed by coordinates with a latitude and a longitude
- **Dissemination radius** expressed by the distance in meters
- **TTL of the information** expressed by the time in seconds

For example, say there is a piece of information related to Toranomon district, which is in downtown Tokyo, and the dissemination radius is set to 1000 meters. The information will be disseminated until it reaches the TTL, within the area indicated as a red shaded circle in Figure 4.1.

Upon disseminating information, iDANS will first query the database for information within its TTL. Next, the distance between the dissemination target and the current location will be measured for each piece of information pulled from the database. If the distance is within the radius, it will then be added to the transmission queue. If not, it will be ignored. When there are multiple pieces of information within the queue, the information with shorter distances will be disseminated first on a priority bases.

In the Decentralized Probe Vehicle System[10], a directional dissemination method was also proposed. However, it was intended to aggregate and distribute specifi-

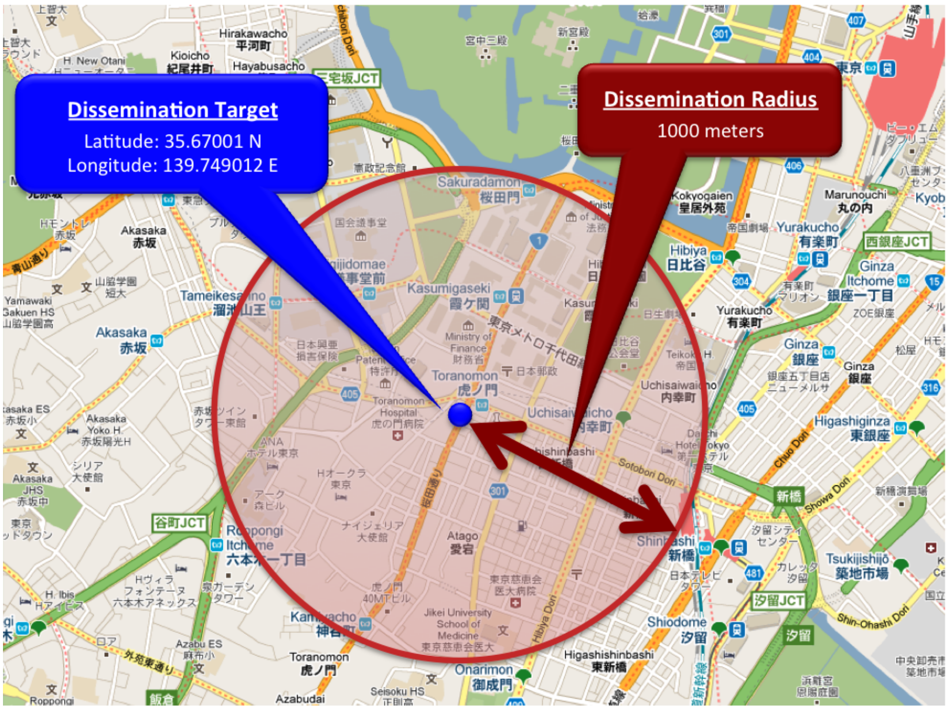

Figure 4.1 Information Dissemination in Toranomon District

cally traffic information. Since iDANS will handle various types of location specific information, this feature will not be implemented.

4.2.2 Reception Based Dissemination

The **Reception Based Dissemination** will enable smartphone nodes with inaccurate location acquisitions to act as repeaters to relay the information from node to node.

From the preliminary experiments in Chapter 3, it was revealed that in-vehicle smartphones are capable of sending and receiving data even if the location sensor is inaccurate. The key idea of Reception Based Dissemination is to make use of such smartphones as repeaters, assuming that the latest piece of data received is the information which is to be disseminated in that particular area.

In the actual dissemination process, iDANS will first query the database for information which is within its TTL and has a reception record. The information will then be added to the broadcast queue. If there were more than one piece of information matching the conditions, information with more recent reception records will be disseminated first on a priority basis.

4.3 Method of Data Transmission

For transmitting data to other nodes, iDANS will use the network interface and protocols indicated in Table 4.1. The User Diagram Protocol (UDP) uses a simple transmission model without implicit hand-shaking dialogues for providing reliability, ordering, or data integrity. Using the broadcast routing scheme over UDP enables independent nodes to transmit data to unspecified destinations when closing in with each other.

Table 4.1 Network Preferences

Network Interface	Wi-Fi (Ad-hoc mode)
Protocol	UDP/IP over IPv4
Routing Scheme	Broadcast

Most smartphones on the market also supports Bluetooth (IEEE 802.15.1). Bluetooth is a wireless interface intended for inter-connecting devices around the user. Thus, it can also be used to transmit datagrams from node to node.

However, its bandwidth and transmission range are limited compared to those of Wi-Fi. It also requires a handshake between devices upon sending and receiving information. From these reasons, Wi-Fi was selected as a network interface for iDANS.

Speaking of the broadcast sequence, information in the broadcast queue would be sent out in an orderly fashion, with an interval in between. If all the information in a queue has been sent away, or if the maximum number of information per send sequence reaches its limit, new sets of information will be requested to the dissemination process.

The transmission interval and the maximum number of information per send queue will be designated by the each individual application based on iDANS.

4.4 Context Modes

This section will describe the two different context modes of iDANS, defined as the **Vehicle Mode** and the **Non-vehicle Mode**.

4.4.1 Vehicle Mode

The **Vehicle Mode** is a context mode indicating that the device is mounted on a vehicle.

In this mode, iDANS will conduct Location Based Dissemination as long as accurate locations can be obtained. If, for some reason, the quality of the location sensor degrades, Reception Based Dissemination will be brought into action.

4.4.2 Non-vehicle Mode

The **Non-vehicle Mode** is a context mode indicating that the device is not mounted on a vehicle. Since smartphones succeeds the functions of cellular phones, it will be possible to make use of smartphones which are not mounted on vehicles (i.e. smartphones held by pedestrians, bicycle riders, and etc.), for enhancing the dissemination process. Figure 4.2 shows a brief image of data transmission from the blue car to the red car with a pedestrian in between.

In this mode, iDANS will conduct Location Based Dissemination as long as accurate locations can be obtained. If, for some reason, the quality of the location sensor degrades, Reception Based Dissemination will be brought into action.

Such nodes may be useful among enhancing the dissemination process, but speaking of the creation of information, they may not be suitable if the application were to handle information specialized for vehicles. If iDANS were to operate under Non-vehicle Mode, the context will be notified to the entire application. The application will then have the authority to decide the eligibility of information generation.

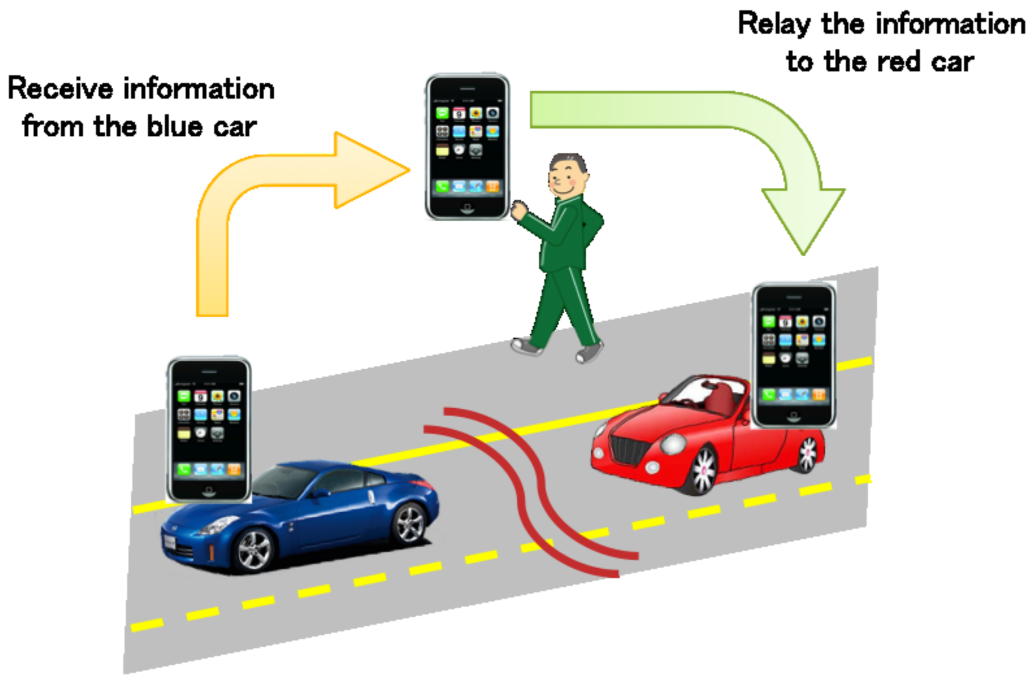

Figure 4.2 The Relay of Information by Pedestrians' Smartphones

4.5 Switching of Context Modes

So far, various methods for detecting the context have been proposed in many researches. For example, Shaka[18] enables the estimation of the movements of a user based on the sensor data from the GPS, the microphone, and the accelerometer. Based on the analysis of sensor data, Shaka can identify if the user is riding on a bicycle, a train, a bus, or a car. It also has the ability to estimate whether the user is standing still, walking, or running when he or she is not riding anything. In this research, dynamic switching may be desired, but not mandatory. Therefore, among the numerous methods available to obtain the device context, iDANS will use switch buttons.

Table 4.2 indicates the 4 different types of operation statuses that can be considered. If iDANS were to operate under nodes in Vehicles Mode with accurate location coordinates, it would be able to generate information and conduct Location Based Dissemination. If accurate location coordinates are unable to be obtained among vehicle nodes, it will conduct Reception Based Dissemination. The same conditions would apply for non-vehicle nodes with inaccurate locations. However, if non-vehicle nodes are able to obtain accurate locations, it will conduct Location Based Dissemination, and be able to generate information depending on the purpose of the application.

Table 4.2 Operation Statuses of iDANS

Condition	**Dissemination Method**	**Message Generation**
Vehicle + Good Location	Location	Yes
Vehicle + Bad Location	Reception	No
Non-vehicle + Good Location	Location	Application Dependant
Non-vehicle + Bad Location	Reception	No

4.6 Platform Modules

This section will describe the details of the modules, which the iDANS iDANS platform consists of. Figure 4.3 indicates the overview structure.

The iDANS platform mainly consists mainly out of five modules in total. The interactions between the modules are as follows.

1. The **Behavior Switcher Module** will notify the device context, the location coordinates, and the dissemination method to the entire application including the data selector. The method of information selection will be changed, accordingly to the quality of location sensors.
2. The **Data Selector Module** will browse through the database and select the information to disseminate on a periodic basis.
3. The **Data Sender Module** will broadcast the information passed from the **Data Selector Module** using Wi-Fi.

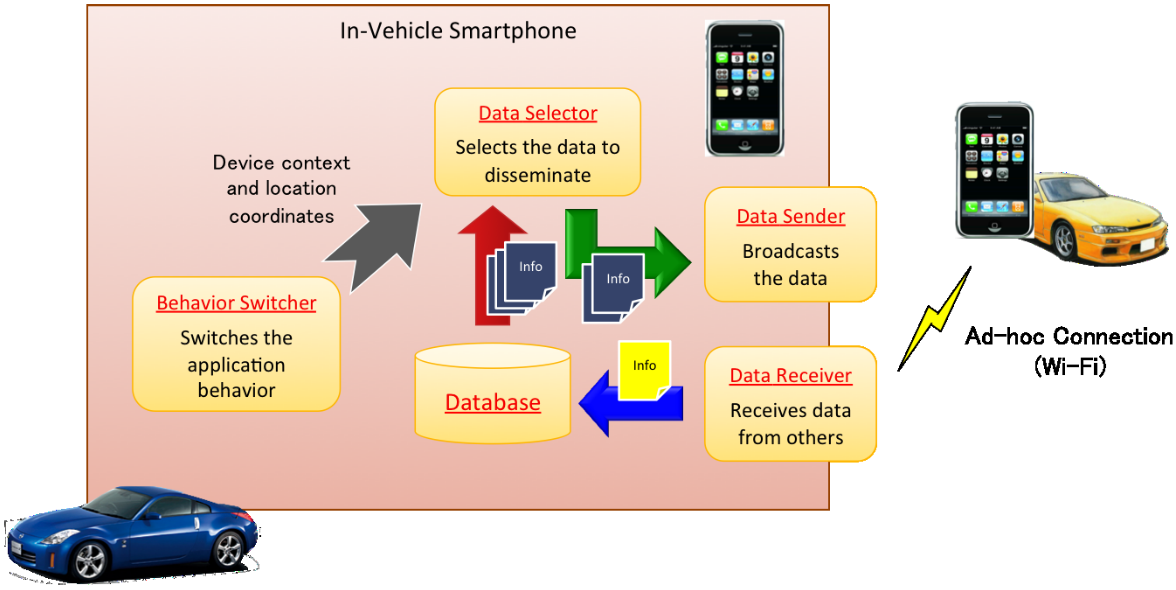

Figure 4.3 Overview Structure of iDANS Platform

4. The information from other nodes is received and stored to the database by the **Data Receiver Module**.

Chapter 5

Implementation

This chapter discusses the implementation of iDANS. In this thesis, iDANS was implemented on iOS for disseminating information generated by iPhones.

5.1 Implementation Environment

The implementation was done using the devices and software listed in Table 5.1. The detailed hardware specifications of the device are listed in Subsection 3.2.1. The iOS SDK[19] is a set of software for developing iOS applications. Its main components include Xcode, which is an integrated development environment (IDE), a C cross compiler for the ARM architecture, a debugging tool, and the Interface Builder for designing the user interfaces. Objective-C[20] is a a reflective, object-oriented programming language developed by Apple that adds Smalltalk-style messaging to the C programming language. It is the primary language used for Apple's Cocoa API, which is used for coding iOS applications.

5.2 Implementation of Platform Modules

This section explains the details of how the modules of iDANS were implemented.

Table 5.1 Implementation Environment of Verification Application

Device	iPhone 4
OS	iOS 4.2.1
SDK	iOS SDK 4.2 on MacBook Pro (Mac OS X 10.6)
Language	Objective-C

5.2.1 Database

In iDANS, SQLite[21] was used as a database platform. SQLite is an open-source software library that implements a transactional SQL database engine that is self-contained, operates without a server, and requires no configurations. It is also supported by the iOS SDK to be used in iOS applications.

In order to store location specific information, the database table was configured with a structure indicated in Table 5.2.

Table 5.2 Database Structure

Field Name	**Data Type**
id	TEXT
gen_time	INTEGER
expire_time	INTEGER
recv_time	INTEGER
gen_latitude	REAL
gen_longitude	REAL
dis_latitude	REAL
dis_longitude	REAL
dis_radius	INTEGER

- **id**
  This field indicates the ID of the node that generated the information. The first 16 characters of the Unique Device ID (UDID) of the device specifies this value. In iOS, a unique 40-character string is allocated to each device as the UDID.
- **gen_time**
  This field indicates the time stamp of the information. The value is represented by the number of seconds elapsed since midnight UTC of January 1st, 1970.
- **expire_time**
  This field indicates the expiration time of the information. The value is represented by the number of seconds elapsed since midnight UTC of January 1st, 1970.
- **recv_time**
  This field indicates the time in when the information was last received. The value is represented by the number of seconds elapsed since midnight UTC of January 1st, 1970.
- **gen_latitude / gen_longitude**
  This field indicates the latitude and the longitude of the place where the information was generated. The values are expressed in degrees by a real number.
- **dis_latitude / dis_longitude**
  This field indicates the latitude and the longitude of the dissemination target. The values are expressed in degrees by a real number.
- **dis_radius**
  This field indicates the dissemination radius. The values are represented by an integer indicating the distance in meters.

In order to make it easier for the application to access the SQLite database, an Objective-C wrapper called the FMDB[22] was used. This wraps up the original SQLite Library for C, and enables the database to be accessed using Objective-C classes and methods.

5.2.2 Behavior Switcher

The behavior switcher module examines the location sensor quality with the device context, and advertises the application if it is to operate under vehicle mode or non-vehicle mode. It also advertises the data selector module if information selections are to be done based on the location or the reception.

The device context; either it is inside the car or not, would be designated by the user with buttons on the screen as shown in Figure 5.1.

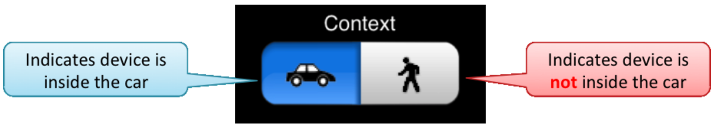

Figure 5.1 Buttons to Change the Device Context

In iOS devices, the location data elements can be obtained by using the Core Location Framework. In the framework, there is a method to acquire the accuracy of the measurements. The accuracy value is represented by an integer indicating a radius of a circle in meters, which shows the area where the device is most likely to be present. For example, if the accuracy value is 10 meters, it indicates that the device is within a 10-meter radius from the location coordinates acquired by the sensor.

Based on the measurement of location sensor accuracy described in Subsection 3.4.3, the difference between the actual location and the sensor values was 10.9 meters at the most when the vehicle was under open air, where GPS signal are assumed to be strong and accurate. From this fact, the threshold of the accuracy value was set to 11 meters.

Figure 5.2 indicates the switching mechanism with a sample code. As described above, the device context and sensor accuracy will be changed accordingly. If any change occurs, the method to switch the behavior will be called. Within the method, the current accuracy and device context will be examined. If the current accuracy value is less than 11 meters, Location Based Dissemination will be conducted. If the device context is set to vehicle mode with accurate locations, data generation will also be enabled. If the accuracy value is over 11 meters, Reception Based Disseminations will automatically be commenced.

```
/* Flag indicating the dissemination method */
BOOL isLocationBased;
/* Flag indicating the device context */
BOOL contextIsCar;
/* Flag indicating the if node can generate information*/
BOOL generateOk;
/* Accuracy of the location sensor */
int currentAccuracy;

/* Called whenever device context or location is updated */
-(void)changeBehavior {

        /* Examine location sensor quality and device context */
        if (currentAccuracy =< 11) {

                if (contextIsCar == TRUE) {
                        generateOk = TRUE;
                }
                isLocationBased = TRUE;

        } else {

                generateOk = FALSE;
                isLocationBased = FALSE;

        }
}
```

Figure 5.2 Switching Mechanism of Behavior Methodssc

5.2.3 Data Selector

The data selector module browses through the database, and selects the pieces of information to transmit according to the method of dissemination (Location Based Dissemination or Reception Based Dissemination).

The selector is called for on a periodic basis, before the send sequence begins. The detailed processes of data selection for each dissemination method are as follows.

- **Data selection under Location Based Dissemination:**
  The selector will first pull the information within its TTL from the database. After that, the distance between the current location and the dissemination target would be measured for each piece of information. The following equations, Equation 5.1 and Equation 5.2, indicate the formula to calculate the distance. This formula is based on the Vincenty Formula[23], which is used generally for calculating the distance between two points on ellipsoids, such as the earth. The parameters are described in Table 5.3. If the distance is within the dissemination radius, the information will be put on a list. Otherwise, it will be discarded. The list will then be sorted in ascending order by the distance. Finally, the top n^{*1} pieces of information from the list would be passed on to the data sender to be broadcast.

$$d = r\Delta\hat{\sigma} \tag{5.1}$$

$$\Delta\hat{\sigma} = \arcsin\left(\frac{\sqrt{(\cos\phi_B \sin\Delta\lambda)^2 + (\cos\phi_A \sin\phi_B - \sin\phi_A \cos\phi_B \cos\Delta\lambda)^2}}{\sin\phi_A \sin\phi_B + \cos\phi_A \cos\phi_B \cos\Delta\lambda}\right) \tag{5.2}$$

*1 Maximum number of data selection in single send sequence (designated by application)

Table 5.3 Equation Parameters

Parameter	**Unit**	**Description**
d	meters	Distance
r	meters	Earth Radius
$\hat{\sigma}$	radians	Angular Difference Between 2 Points
ϕ_A	radians	Latitude of Point A
ϕ_B	radians	Latitude of Point B
$\Delta\lambda$	radians	Angular Difference Between 2 Longitudes

- **Data selection under Reception Based Dissemination:**
  The selector will query the information from the database which is within its TTL, and also has a reception record. The results will then be sorted in descending order by the reception time. Finally, the top n[*2] pieces of information from the list would be passed on to the data sender to be broadcast.

5.2.4 Data Sender

The tasks of the data sender module are to broadcast the information passed on by the data selector module. Upon sending the information, the data sender module will examine the sending interval designated by the application.

In the actual sending sequence, the messages passed from the data selector will be sent one by one in a orderly fashion, with an interval in between. After all the messages have been transmitted, the sender will request the data selector for another set of information.

[*2] Maximum number of data selection in single send sequence (designated by application)

5.2.5 Data Receiver

The data receiver module undertakes the role of listening to the socket and receives the messages.

When a message is received, the data receiver first examines the origin of the packet. When a node transmits a broadcast packet, it will be delivered to all the nodes within the same network segment, including itself. Therefore, the data receiver will discard any messages whose origin matches its own IP address.

If it is determined that the delivered messamge was sent by another node, the receiver module then inquires the database if it already contains the same information indicated in the message. If the database has the information, the receiver will update the receipt time of the correspondent information within the database. If not, it will store the data to the database as a new piece of information.

Chapter 6

Evaluation

In order to evaluate and verify the effectiveness of the proposed platform, iDANS, series of tests and simulations were done. This chapter discusses the methods and results of those tests and simulations.

6.1 Evaluation Overview

In this thesis, the proposed platform, iDANS, was evaluated from the following aspects.

- **Correct operations of location based dissemination**
  Verify that iDANS properly selects and transmits unexpired information within its dissemination radius.
- **Correct operations of reception based dissemination**
  Verify that iDANS properly selects and transmits unexpired information which has the most recent reception records.
- **The effectiveness of the proposed dissemination methods**
  Compare the proposed dissemination methods with a complete random dissemination, and verify that it is effective in disseminating information rapidly within the designated area.

In order to verify the functions of each behavior method, a test using actual smartphones was conducted. Meanwhile, simulations were done in order to examine the effectiveness of proposed dissemination methods.

6.2 Operation Verification

This section describes the details of the operation verification test.

6.2.1 Application for Operation Verification

In order to verify the correct operations of iDANS, a simple verification application based on iDANS was implemented on iOS. This application enables drivers to genarate open parking space information using iOS devices, and share them by using the iDANS platform. Figure 6.1 indicates the specific usage scenario of this application.

1. Drivers leaving the parking lot would create open parking space information. Upon leaving the lot, the drivers would record their location as an open space for the next driver.
2. The information would be shared between nodes while vehicles pass by each other.
3. When a vehicle heading to the parking lot receives the information, the location would be indicated on the map.

Figure 6.2 shows the screen dump of this application. A button on the user interface would trigger the actual generation process of open parking space information. If the application is under non-vehicle mode or has low accuracy values, the button will not be shown. When the button is pressed, the current location will be registered to the database as an open parking space. When a piece of information is created or received, it will be plotted on the map.

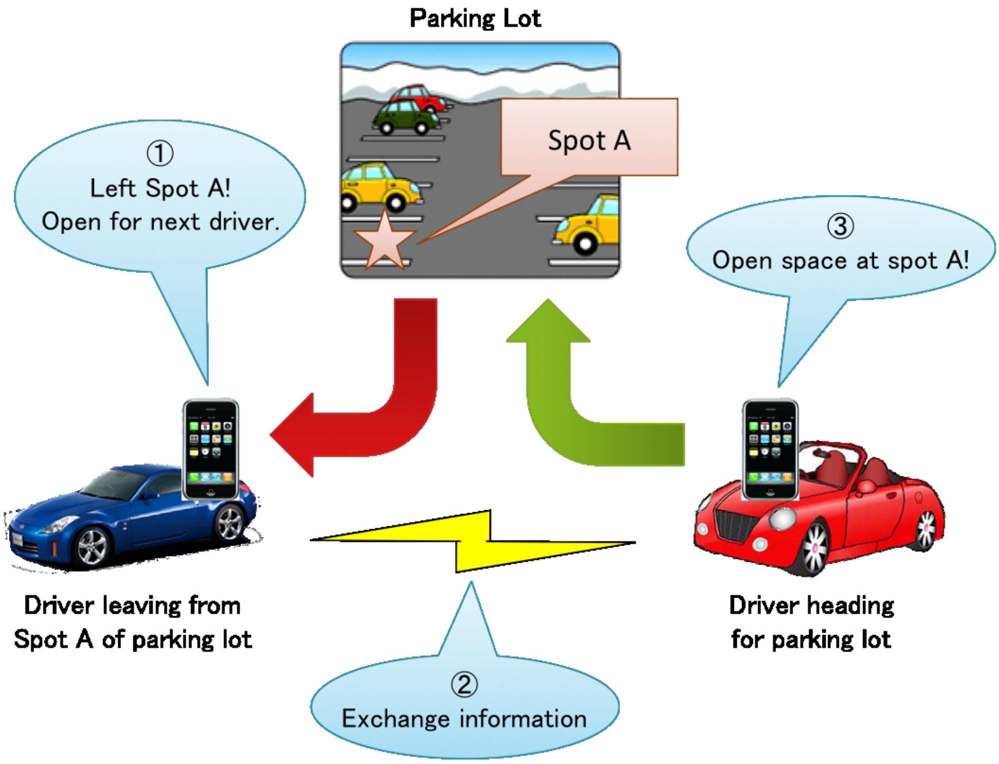

Figure 6.1 Usage Scenario of Prototype Application

In this application, the location of each open space will also be registered as the dissemination target. The dissemination radius*1, the TTL*2, the send interval*3, and the maximum number of data per send sequence*4 will be assigned by the user from the preference screen.

In order to check the operations afterwards, logging functions were implemented within the application. If any information were to be created, broadcast, or received, a detailed description of the event would be recorded in the log.

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*1 10 to 2000 meters
*2 1 to 20 minutes (60 to 1200 seconds)
*3 100 to 1000 milliseconds
*4 1 to 20 pieces of information

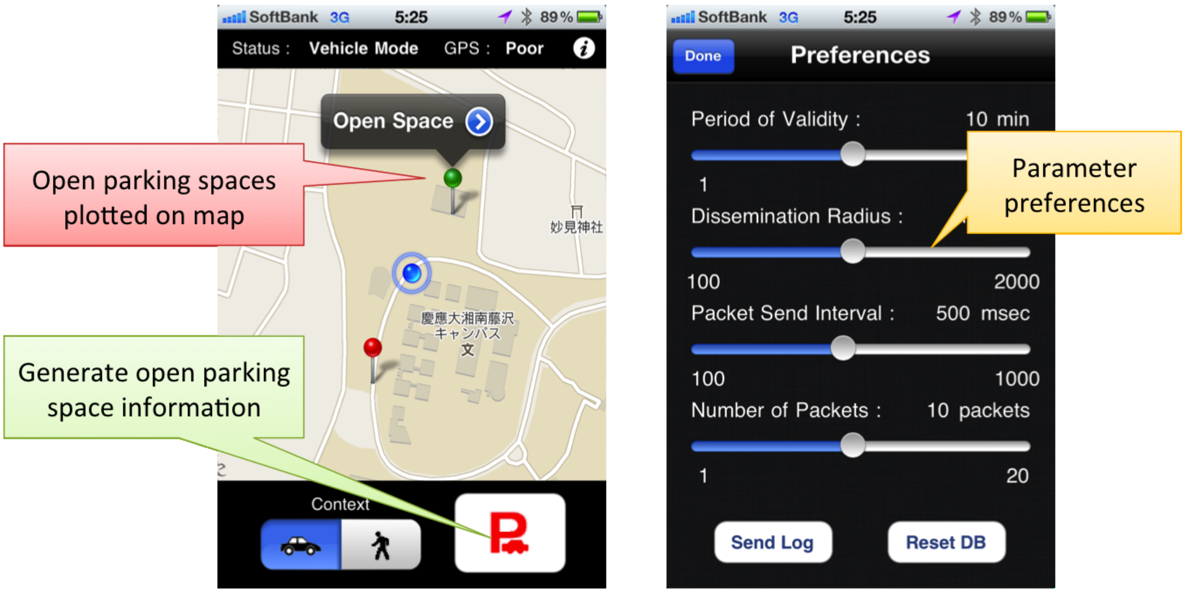

Figure 6.2 Screen Dump of the Verification Application

6.2.2 Verification Scenario

The goal of this verification would be to check the correct operations of iDANS upon disseminating information. If iDANS were to conduct Location Based Dissemination, information with the nearest dissemination targets should be sent. Also, it must not be unexpired in terms of the TTL. On the other hand, if iDANS were to conduct Reception Based Dissemination, information that is still valid in terms of the TTL, and has the most recent reception records should be selected and transmitted.

In order to verify the operations, a data transfer test was conducted between two vehicles equipped with in-vehicles smartphones, and two relay nodes held by pedestrians. One of the two vehicles would be Vehicle A, a vehicle moving out from a parking space on the premise of Keio University Shonan Fujisawa Campus (SFC) in Fujisawa, Japan. The other would be Vehicle B, a vehicle heading for the campus looking for a place to park.

Figure 6.3 indicates the flow of the test. The test will begin with Vehicle A recording its current location upon leaving the parking space near the gymnasium. Upon leaving the campus premise, Vehicle A will attempt to send the information to the pedestrians, who are wandering around the north entrance gate. The pedestrians will then attempt to pass the information to Vehicle B, which will be approaching the campus a while after Vehicle A have driven away.

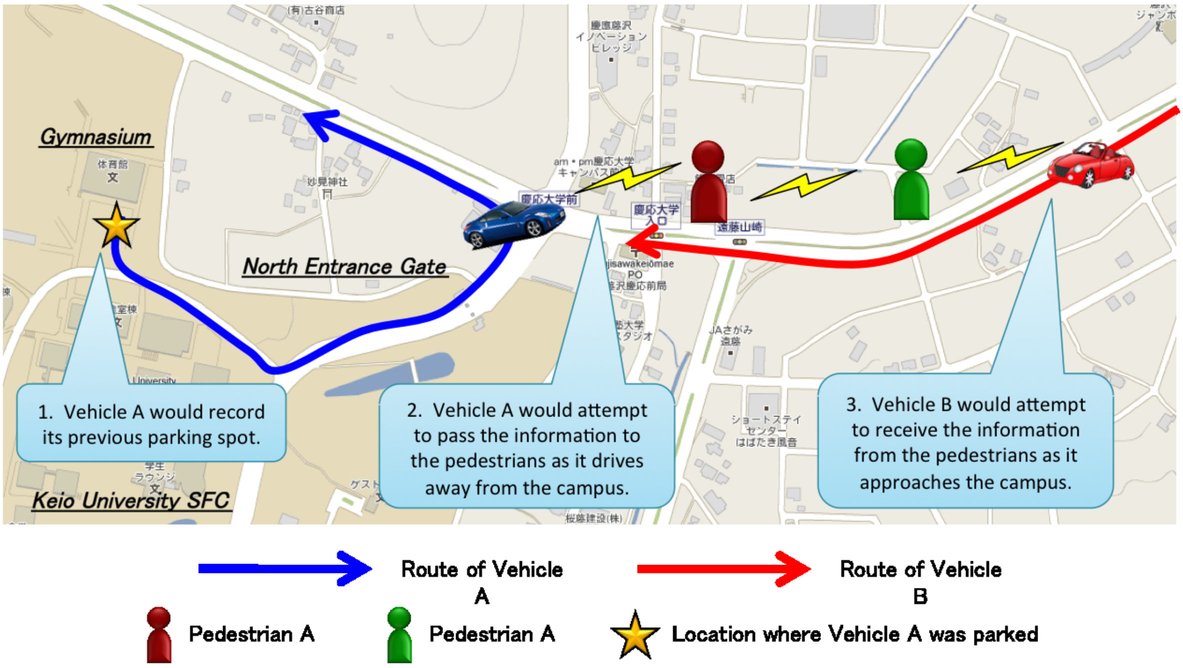

Figure 6.3　Flow of the Test

In this test, 8 pieces of dummy data were registered to the database in advance. The dummy data consists of 4 pieces of unexpired data, which should be disseminated somewhere away from the university campus, and 4 pieces of expired data.

Correct operations of Location Based Dissemination may be verified, if Vehicle A successfully in filters out the dummy data through the selection process. If the two relay nodes successfully transmits only the information that has reception records, the correct operations of Reception Based Dissemination may also be verified.

If both vehicles and relay nodes were to operate correctly, the two relay nodes would only transmit the data created by Vehicle A before leaving the parking lot.

Also, Vehicle B would receive the information indicating the open parking space from the relay nodes.

6.2.3 Test Conditions

The detailed conditions and parameters of the actual test are as listed in Table 6.1.

Table 6.1 Conditions of the Verification Test

In-vehicle Device	iPhone 4 (iOS 4.2.1)
Pedestrians' Device	iPhone 4 (iOS 4.2.1)
Dissemination Radius	1000 m
TTL	10 min.
Packet Transmission Interval	500 msec.
Maximum Number of Data Selection Per Send Sequence	10

Speaking of the validity of the parameters, the dissemination radius of 1000 meters should cover the entire area near the campus including the north entrance gate. Also, the 10 minute TTL should be more than enough when considering the data transfer from Vehicle A to Vehicle B at the entrance gate, since it will not take more than a minute or two for Vehicle A to travel from the parking lot to the gate. The maximum number of data selection should also meet the requirements, since the nodes in this test will not handle no more than 9 pieces of information (8 dummy data and 1 piece of information generated by Vehicle A). On the other hand, the 500-millisecond intervals between transmissions may seem too short in terms of avoiding packet collisions. This may be true and critical when there are numerous nodes within the transmission range. However, in this test, the number of nodes is limited to four. Considering the limited number of nodes within the transmission range, it is unlikely that packet collisions will become a major issue in this particular test.

As for this test, the location sensors were manually turned off in the pedestrians' nodes, in order to manually enable Reception Based Dissemination.

6.2.4 Results

In the test, Vehicle B was successful in receiving the open parking space information created by Vehicle A from the relay nodes. The details of the data transmission were examined by observing the event logs of each node. Figure 6.4 indicates examples of an event record in a log.

```
/* Create Event*/
1292741904,35.389524,139.426760,CREATE,35.389524,139.426760,
d626193917a6399c,1292741904,1292742504,1000,,,,,

/* Send Event (Location Based Dissemination) */
1292741998,35.389846,139.431530,SEND,35.389524,139.426760,
d626193917a6399c,1292741904,1292742504,1000,LOCATION,0,696.8,500,10

/* Send Event (Reception Based Dissemination) */
1292743229,35.389795,139.433745,SEND,35.389432,139.426676,
d626193917a6399c,1292743132,1292743732,1000,RELAY,0,1292743223,500,10

/* Receive Event*/
1292743230,35.389795,139.433745,RECEIVE,35.389432,139.426676,
d626193917a6399c,1292743132,1292743732,1000,,,,,
```

Figure 6.4 Examples of Event Records

Based on the event log, Vehicle A was successful in measuring the distance between the current location and the dissemination target. It was also successful in filtering out the dummy data. Meanwhile, the two relay nodes were successful in properly transmitting only the information with reception records.

6.3 Effectiveness of the Proposed Dissemination Methods

The main goal of iDANS is to disseminate information rapidly among vehicles within a designated area. This section discusses the details of the simulation that was conducted to measure the effectiveness of the proposed dissemination methods upon meeting the goal.

6.3.1 Overview of the Simulator

In order to simulate the dissemination process between vehicles in an urban environment, a network simulator called The Opportunistic Network Simulator (The ONE)[24] was used. The ONE is an open source network simulator written in Java, released under the GPLv3[25] license. It enables the evaluation of message routing and forwarding schemes of Delay and Disruption Tolerant Networks (DTN).

DTN refers to a network of nodes under an environment where there are long delays and topology disruptions, which are not tolerable in conventional networks. Speaking of VANETs, they are classified as a typical example of DTNs, since the network topology and the connection status between nodes in VANETs are highly likely to change continuously as the vehicles move.

In the simulation, a mobility scenario module called the *Helsinki City Scenario (HCS)* was used. The HCS replicates the city of Helsinki, Finland on the simulator as shown in Figure 6.5.

Nodes will be moving along the map of Helsinki, which is 3.5 km long and 4.5 km wide. The path of nodes would be selected based on the Shortest Path Movement Model[24]. In this movement model, the nodes will move toward the randomly selected destination at a constant speed. When a node arrives at its destination, it will pause there for certain amount of time, before heading to the next randomly selected destination. The destination, path, speed, and pause time of the nodes would be randomly selected based on the following rules.

- The destination would be selected randomly from the list of POIs (point-of-

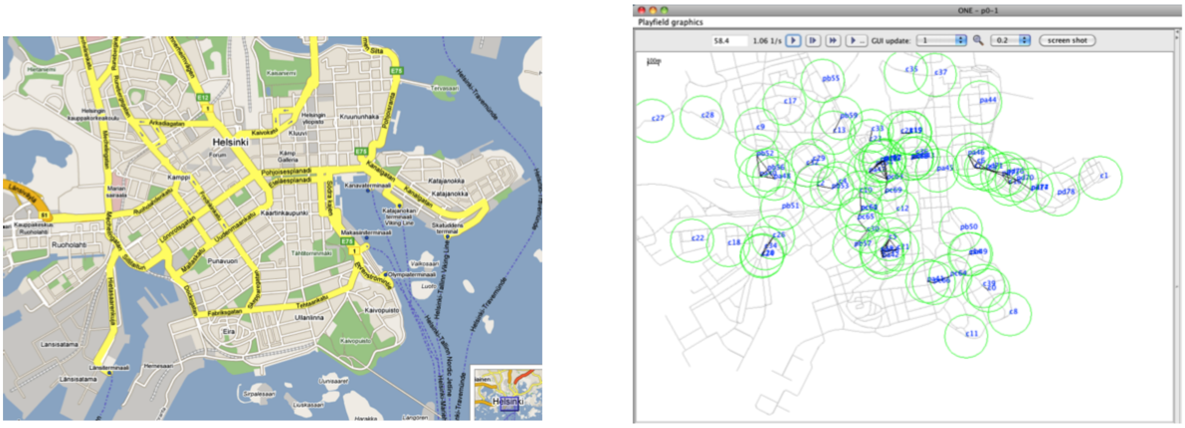

Figure 6.5 Map of Helsinki in the Simulator

interest) registered in the HCS.

- Once the destination is selected, the node will move along the shortest path to the destination, based on the Dijkstra's Algorithm[26].
- The speed and pause time would be selected from the range of values specified the by the user. Each time the node pauses at its destination, new values would be randomly selected based on the normal distribution model.

6.3.2 Simulation Environment

Before conducting the simulation, the map was first segmented in 63 cells[*5] as shown in Figure 6.6. For each cell, 25 pieces of information were created. These 25 pieces of data were configured for dissemination within the perimeter of each cell. To be specific, the dissemination target was set to a point within the cell, and the dissemination radius was set to 500 meters.

Then, a total of 168 vehicles nodes equipped with all 1575 pieces of information[*6], were placed on the map. This number was calculated assuming that 1% of all vehicles registered to the city of Helsinki[27] are running iDANS based applications

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[*5] Size of cell: 500 m × 500 m

[*6] 25 pcs. of data × 63 cells in total

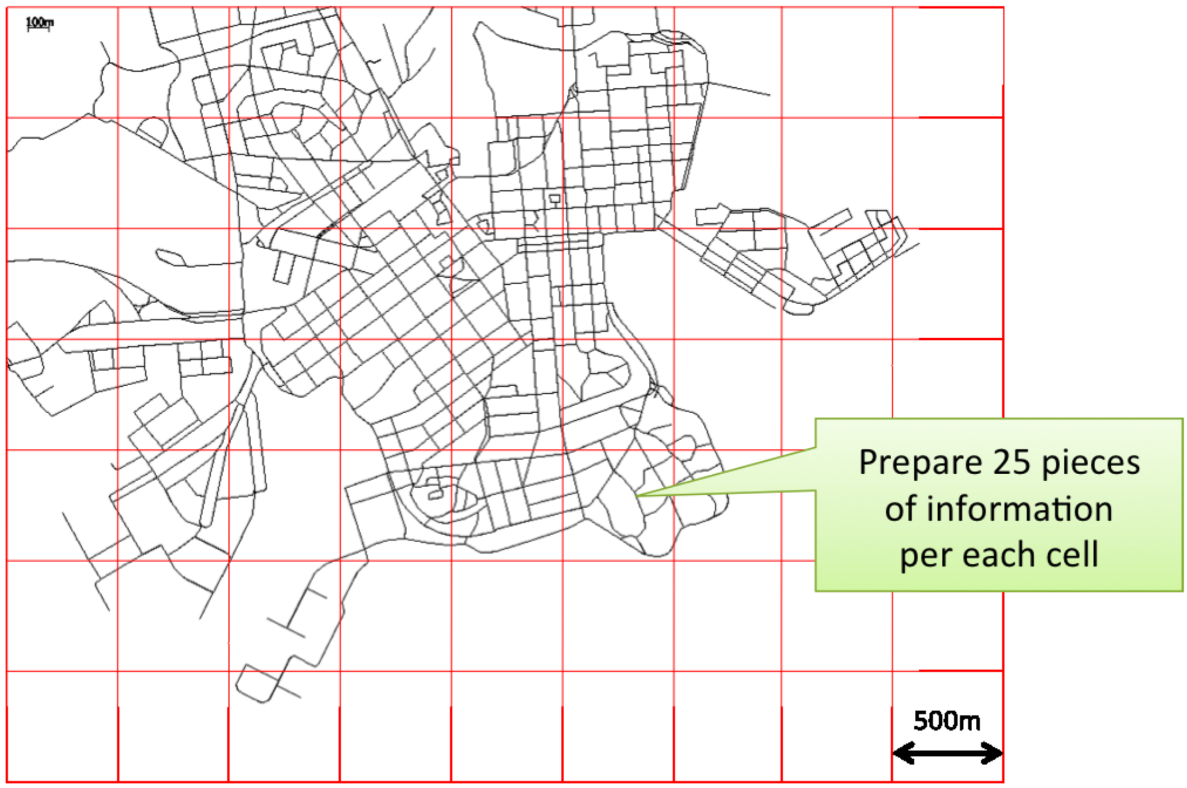

Figure 6.6 Segmentation of the Map

on smartphones. The vehicle nodes would then move along the map, disseminating information based on the iDANS platform.

Finally, an evaluation vehicle with an empty database was prepared and placed on the map. The evaluation vehicle would then move along the cells, collecting information transmitted by others. In order to examine the effectiveness, the reception ratio was measured for each cell the evaluation vehicle had passed. The reception ratio in this case refers to the ratio of successfully received information relevant to each cell. For example, if the reception ratio was 10% while passing through a particular cell, it indicates that the evaluation vehicle was successful in receiving 5 out of the 25 pieces of information relevant to the cell. Higher the reception rate is, the more successful in receiving relevant information.

6.3.3 Configurations of Mobile Nodes

The mobile nodes in this simulation were configured with the following parameters indicated in Table 6.2.

Table 6.2 Configurations of Mobile Nodes

Speed	10-50 km/h
Pause Time	0 to 120 seconds
Transmission Range	100 m
Bandwidth	5.2 $Mbps$

In the simulator, connections between nodes are either on or off. When two nodes come across each other within the given transmission range, a valid connection will be initiated. Connection will remain effective until the two nodes move apart beyond the transmission range. While connections are up, 100% of the bandwidth is assumed usable.

Based on these facts, the transmission range was set to 100 meters, considering the packet loss rate within a 100-meter radius, which was approximately 5%. On the other hand, the bandwidth was set to 5.2 Mbps, considering the actual throughput between nodes 100 meters apart.

6.3.4 Simulation Conditions

In this simulation, the reception rate was measured under the following conditions.

- **0 Relay Nodes**

  All 168 nodes conduct Location Based Dissemination.
- **20% Relay Nodes**

  34 out of 168 nodes conduct Reception Based Dissemination. Others conduct Location Based Dissemination.

- **40% Relay Nodes**
  68 out of 168 nodes conduct Reception Based Dissemination. Others conduct Location Based Dissemination.
- **Random Dissemination**
  All 168 nodes randomly disseminate information without any logic.

For each condition, 100 trials were conducted, and the average reception ratios were calculated. In each of the conditions, the number of relay nodes was changed to see how the Reception Based Dissemination would affect the reception rates. Also, the reception rate under random dissemination was measured as a reference value.

6.3.5 Simulation Results

Figure 6.7 indicates the average reception ratios while the evaluation node passed along a single cell. The average reception ratio was approximately 11% when all the nodes conducted random dissemination. On the other hand, the average reception ratio was approximately 39%, when the Location Based Dissemination was conducted in all nodes. Furthermore, the average reception ratio was approximately 37%, when 40% of the nodes conducted Reception Based Dissemination.

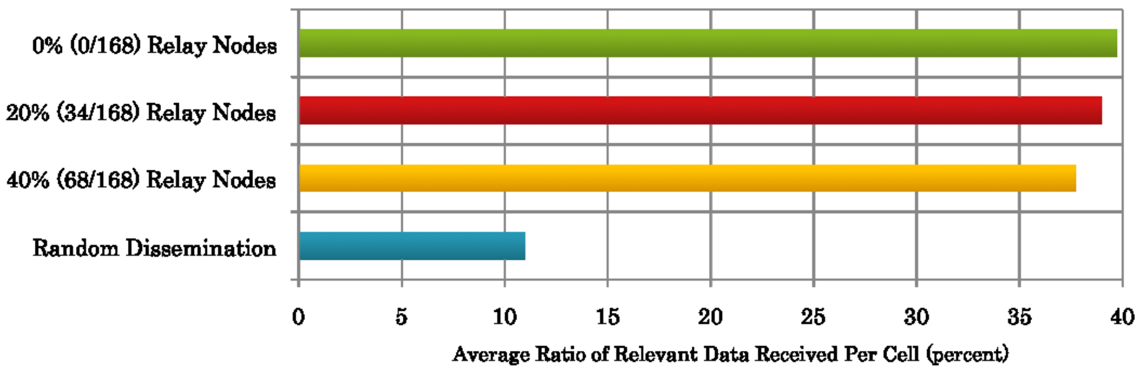

Figure 6.7 Average Reception Ratios

Figure 6.8 indicates the average reception ratios by the elapsed time in a single cell. When all nodes conducted the Location Based Dissemination, the average reception ratio rose continuously as the time elapsed. The increase rate was not as high when relay nodes were present, but the difference was relatively small. On the other hand, the average reception ratio remained mostly level at approximately 11% when all the vehicles conducted random dissemination.

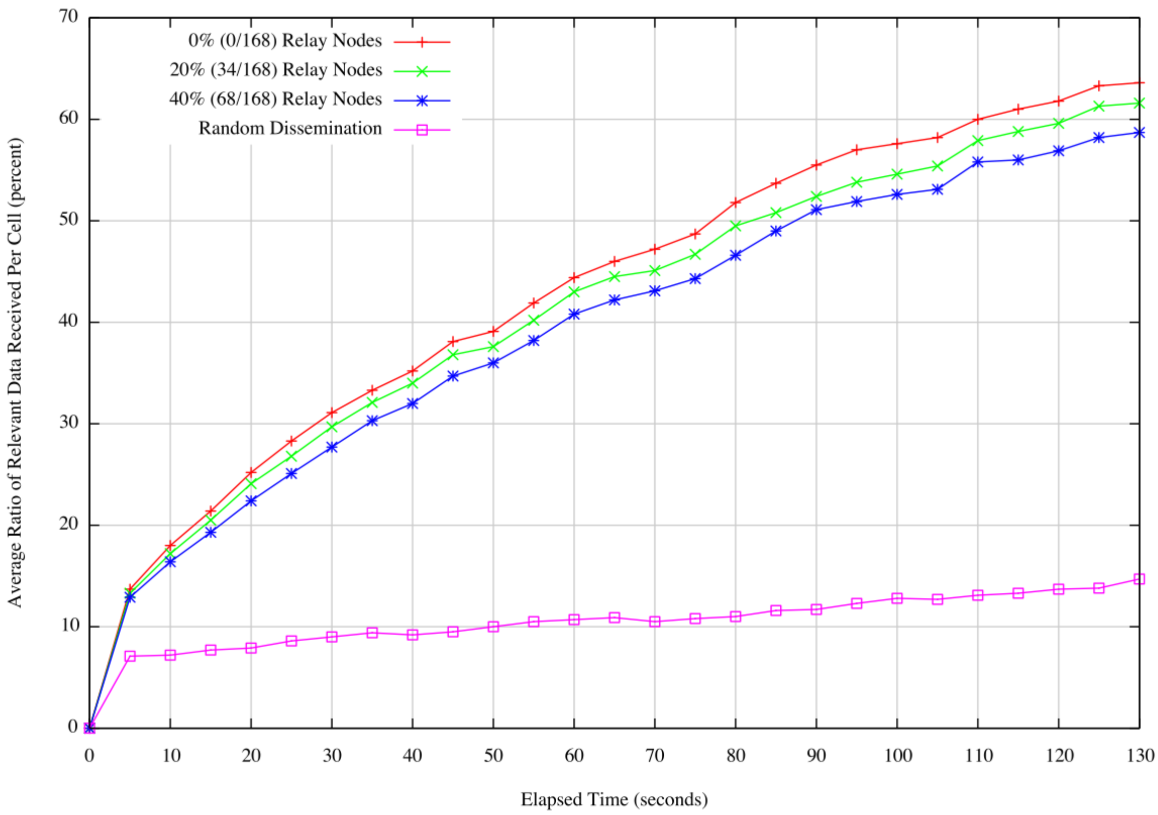

Figure 6.8 Average Reception Ratio Per Elapsed Time

6.4 Considerations

Based on the results of the verification test, the correct operations of the Location Based Dissemination and the Reception Based Dissemination were verified. In the simulation, the dissemination methods of iDANS were compared to a random dissemination method without any logic. As a result, the methods of iDANS were successful in disseminating up to 5.5 times more data within the designated area. Also, the efficiency degradation brought down by relay nodes was very limited. From these facts, the dissemination methods of iDANS is effective in disseminating more information rapidly among vehicles within a designated area.

Chapter 7

Conclusion

7.1 Outcome

In this thesis, an ad-hoc information dissemination platform for in-vehicle smartphones called iDANS was proposed. The proposed platform enables the rapid dissemination of location specific information among vehicles within a designated area. It also makes use of smartphones that cannot acquire the current location accurately as relay nodes.

The correct operations of the proposed dissemination methods were verified using a test application implemented iPhones. Also, simulations revealed that the iDANS is effective in terms of disseminating more information rapidly within a designated area.

7.2 Future Work

This section discusses the points of this research that remains to be solved in the future.

7.2.1 Large-scale Experiments in a Real World

In this thesis, the effectiveness of iDANS was verified based on simulation results. The next phase of this research would be to conduct large-scale verification experiments using in actual smartphones and vehicles in a real world.

7.2.2 Implementation of Methods to Reduce Packet Collisions

The proposed platform in this thesis does not implement methods, which enable dynamically changing of transmission intervals, depending on the quantity of nodes within the transmission area. Thus, packet collisions will be likely to increase when a large number of nodes were to be deployed within a small range. Since packet collisions are known as factors that decrease the efficiency of communications in ad-hoc networks, a method to avoid such cases will be necessary.

7.2.3 Implementation of a Feasible Method for Exchanging Multimedia Contents

As discussed earlier, one of the key features of smartphones is the ability to handle multimedia contents at ease. In order to benefit from such feature, a feasible method which enable exchanges of multimedia contents over VANETs is required.

Bibliography

[1] Keisuke Uehara. Probe vehicle system : Getting environmental information using vehicle sensors. In *IPSJ Magazine*, volume 9, pages 1144–1149. Information Processing Society of Japan, 2010. 1.1.1

[2] TOYOTA Media Service Corporation. G-BOOK. `http://g-book.com/pc/default.asp`. 1.1.1

[3] Nissan Motor Co.,Ltd. Carwings. `http://drive.nissan-carwings.com/WEB/index.htm`. 1.1.1

[4] Honda Motor Co., Ltd. internavi Premium Club. `http://www.honda.co.jp/internavi/`. 1.1.1

[5] Wi-Fi Alliance. Wi-Fi. `http://www.wi-fi.org/discover_and_learn.php`. 1.1.1

[6] Yano Research Institute Ltd. 2008-2009 smartphone/umpc/pnd worldwide market trend survey, 2009. 1.1.2

[7] Lars Wischhof, André Ebner, and Hermann Rohling. Information dissemination in self-organizing intervehicle networks. In *IEEE Transactions on Intelligent Transportation Systems*, volume 6, pages 90–101. IEEE Intelligent Transportation Systems Society, March 2005. 2.1.1

[8] Jun Tsukamoto, Masashi Saito, Takaaki Umedu, and Teruo Higashino. Intervehicle ad-hoc protocol rmdp for acquiring preceding traffic information and its performance (its). *Transactions of Information Processing Society of Japan*, 47(4):1248–1257, April 2006. 2.1.2

[9] Masaaki Sato, Takaaki Ishida, Ryota Horiguchi, Katsumasa Shimizu, Hitoshi

Haruta, Koji Wada, Keisuke Uehara, and Jun Murai. Evaluation of road traffic information generation algorithm for decentralized probe vehicle system. In *Transactions of Information Processing Society of Japan*, 2008. 2.1.3

[10] Takaaki Ishida, Masaaki Sato, Masayoshi Imaike, Ryota Horiguchi, Koji Wada, Keisuke Uehara, and Jun Murai. Development and evaluation of data transmission algorithms for decentralized vehicle probe systems. In *KEIO SFC JOURNAL*, volume 7, pages 38–55, 2007. 2.1.3, 2.2, 3, 4, 4.2.1

[11] Jedrzej Rybicki, Björn Scheuermann, Markus Koegel, and Martin Mauve. PeerTIS: a peer-to-peer traffic information system. In *VANET '09: Proceedings of the sixth ACM international workshop on VehiculAr InterNETworking*, pages 23–32, 2009. 2.1.4

[12] Sylvia Ratnasamy, Paul Francis, Mark Handley, Richard Karp, and Scott Shenker. A scalable content-addressable network. In *Proceedings of the 2001 conference on Applications, technologies, architectures, and protocols for computer communications*, SIGCOMM '01, pages 161–172, New York, NY, USA, 2001. ACM. 2.1.4

[13] Apple Inc. iPhone 3GS. http://www.apple.com/jp/iphone/iphone-3gs/. 3.2.1

[14] Apple Inc. iPhone 4. http://www.apple.com/jp/iphone/. 3.2.1

[15] Apple Inc. iPad. http://www.apple.com/jp/ipad/. 3.2.1

[16] Jani Jarvinen and Javier DeSalas and Jimmy LaMance. Assisted GPS: A Low-Infrastructure Approach. http://www.gpsworld.com/gps/assisted-gps-a-low-infrastructure-approach-734. 3.2.1

[17] Jason R. McNeil. WiFi Bench. http://jasonrm.net/code/WiFiBench/, 2010. 3.3.2

[18] Arei Kobayashi, Kenji Iwamoto, and Satoshi Nishiyama. Shaka : Method for estimating user movement using mobile phone. *IEICE Technical Report. MoMuC, Mobile Multimedia Communication*, 108(44):115–120, May 2008. 4.5

[19] Apple Inc. iOS Dev Center. http://developer.apple.com/devcenter/ios/index.action. 5.1

[20] Apple Inc. Object-Oriented Programming with Objective-C. http:

//developer.apple.com/library/mac/#documentation/Cocoa/Conceptual/OOP_ObjC/Introduction/Introduction.html. 5.1

[21] SQLite. About SQLite. http://www.sqlite.org/about.html. 5.2.1

[22] Gus Mueller. FMDB. https://github.com/ccgus/fmdb. 5.2.1

[23] Thaddeus Vincenty. Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. In *Survey Review*, volume 23, pages 83–93, Kingston Road, Tolworth, Surrey, April 1975. Directorate of Overseas Surveys. 5.2.3

[24] Ari Keränen, Jörg Ott, and Teemu Kärkkäinen. The ONE Simulator for DTN Protocol Evaluation. In *SIMUTools '09: Proceedings of the 2nd International Conference on Simulation Tools and Techniques*, New York, NY, USA, 2009. ICST. 6.3.1, 6.3.1

[25] Free Software Foundation. Gnu general public license version 3. http://www.gnu.org/licenses/gpl-3.0.html, June 2007. 6.3.1

[26] Edsger W. Dijkstra. A note on two problems in connexion with graphs. In *Numerische Mathematik*, volume 1, pages 269–271, 1959. 6.3.1

[27] City of Helsinki. Facts about helsinki, 2006. 6.3.2

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