Implementation of a Location-Aware Information Delivery Method for a Vehicular Application using Digital Terrestrial Broadcasting

Kenya Sato†, Takahiro Koita† and Akira Fukuda‡

†Department of Information Systems, Doshisha University
1-3 Tatara-Miyakodani, Kyotanabe-Shi, Kyoto, 610-0321, Japan
†{ksato, tkoita}@mail.doshisha.ac.jp
‡Graduate School of Information Science and Electrical Engineering, Kyusyu University
6-1 Kasuga-Koen, Kasuga-Shi, Fukuoka, 816-8580, Japan
fukuda@f.csce.kyushu-u.ac.jp

ABSTRACT

"One seg" or one-segment digital terrestrial broadcasting service was launched in Japan in 2006. One current use of one-segment broadcasting is providing digital TV programs to mobile phones, portable devices, car navigation systems, and so on. Navigation systems generally provide drivers with point-of-interest information, traffic information, weather reports and so on through cellular phone networks as well as driving directions. The one-segment broadcast method is an additional candidate for disseminating location-aware information for vehicular applications. Using the broadcast method to deliver location-aware information is more scalable and less expensive in comparison with cellular phones. We have proposed a cache system especially for caching location-aware information for broadcast data delivery. In this paper, we implement the emulation system to evaluate this location-aware information delivery method for a concrete vehicular application that delivers geographic road map data to a car navigation system.

Keywords: Digital broadcasting, location-aware, vehicular application, ITS.

1 INTRODUCTION

One-segment digital terrestrial broadcasting service [1] began in Japan on April 1, 2006. One-segment broadcasting, also called "one seg," refers to the single segment set aside out of a total of 13 segments for customizable mobile broadcasting in each of Japan's home TV terrestrial digital channels. One current use for one-segment broadcasting is digital TV programs for mobile phones, portable devices, car navigation systems, and so on. In addition, data broadcasting has been specified [2] in the Association of Radio Industries and Businesses (ARIB), and some other application examples have also been proposed [3].

Current navigation systems generally provide drivers with point-of-interest information, traffic information, weather reports, and so on through cellular phone networks. The one-segment broadcast method is an additional candidate for disseminating location-aware information for vehicular applications. Using this broadcast method to deliver location-aware information is more scalable and less expensive in comparison with cellular phones. However, this broadcast delivery method has the drawback that a mobile host, which is part of an in-vehicle computer system, needs to wait for the required data items to appear on the broadcast channel.

In order to reduce the time the mobile host needs to wait, and to receive and store data effectively on the mobile host, a caching mechanism is necessary. The mobile host does not have to wait for the data item to appear on the broadcast channel if the data is stored in a cache. The idea of caching broadcast data is not new and there are existing proposals for data delivery to a mobile host [4]. Generally, a least recently used (LRU) method has been adopted for data replacement policies, although Acharya et al. proposed the PIX and PT methods [5] to invalidate useless data in a cache and prefetch useful data among the broadcast data. Although these methods are optimal policies, they are impractical since they all require complete knowledge of the access probabilities and comparisons of each value for all cached data. Barbara et al. proposed another strategy [6] in which broadcast data are categorized into synchronous / asynchronous, and stateful / stateless. Jing et al. proposed a method based on bit sequences [7] to effectively send invalidation reports that are organized as a set of bit sequences with an associated set of timestamps.

We believe that the methods described above are not always effective for receiving location-aware information on a mobile host and that there could be more effective caching methods for a vehicular application. We have proposed a cache system [8] especially for caching location-aware information through broadcast data delivery. With this cache system, a data item a mobile host is interested in is prefetched and replaced at an appropriate time according to the mobility specifications, which is a schedule that outlines the route a mobile host is expected to travel along. In this paper, we implement this emulation system to evaluate a location-aware information delivery method for a concrete vehicular application that delivers geographic road map data to a car navigation system.

2 ONE-SEGMENT DIGITAL TERRESTRIAL BROADCAST

The digital terrestrial broadcasting system in Japan applies ISDB-T (Integrated Services Digital Broadcasting - Terres-

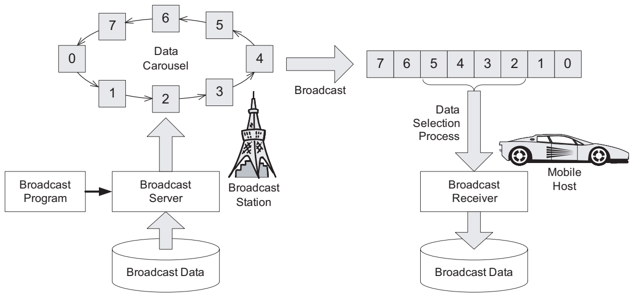

Figure 1: Broadcast model outline

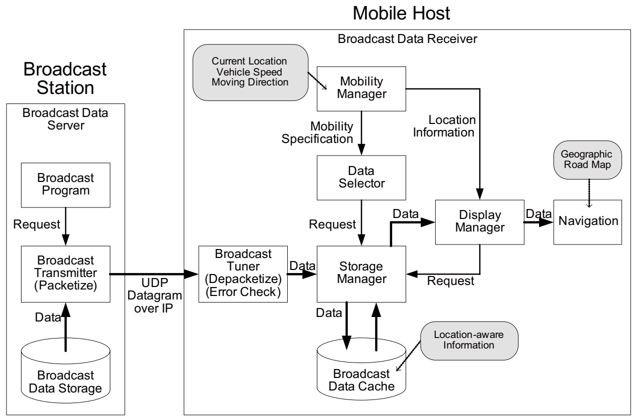

Figure 2: Emulation model for data transfer

trial) with OFDM (Orthogonal Frequency Division Multiplex), which is the standard for digital terrestrial television broadcasting and digital terrestrial sound broadcasting. OFDM modulation is effective for single frequency networks, and is robust to multipath interference.

The signal in the transmission channel consists of 13 OFDM segments (6MHz spectrum) whose parameters can be selected independently of each other, for example, one HDTV (12 segments) + mobile service (1 segment), or three SDTV (3×4 segments) + mobile service (1 segment). The one-segment digital broadcasting service uses the middle segment of the 13 segments to transmit, and enables high error tolerant reception for mobile receivers. One current service of the one-segment broadcasting is digital TV programs transmitted in a H.264 (MPEG-4 AVC) format at QVGA (320×240 pixels) resolution. The total bit rate is approximately 312kbps with DQPSK modulation and 1/2 inner convolution error correction, 416kbps with DQPSK modulation and 2/3 inner convolution error correction, 624kbps with 16QAM modulation, and 1.4Mbps with 64QAM modulation. Since the ISDB-T specification includes a data broadcasting function, we believe that the service would be applicable for delivering location-aware information to vehicular applications.

3 BROADCAST DATA MANAGEMENT

3.1 Broadcast Scheme

Figure 1 shows the outline of data dissemination from a broadcast station to a mobile host. The broadcast data items are location-aware information such as point-of-interest information, traffic information, weather reports, and so on. The broadcast station repeatedly transmits broadcast data items as a data carousel during the scheduled broadcasting time period. The caching of data items in a mobile host's local storage is important for improving retrieval performance and for data availability. The mobile host receives and caches data items in its local storage, and the data items become available before the start of a scheduled broadcasting period. Therefore, the mobile host does not have to wait for the data items to appear on the broadcast channel if the data is stored in the cache. Generally, due to the limited size of local storage in the mobile host to cache broadcast data items, the mobile host selects only those data items it needs, and the other data items are not stored in the local storage.

3.2 Emulation System

To study location-aware information delivery method using data broadcasting, we implemented the emulation model shown in Figure 2. The emulation model consists of two kinds of components: a broadcast data server as a broadcast station; and a broadcast data receiver on a mobile host. Both the server and receiver functions are implemented as application programs on PCs. These PCs are connected to a single IP network over Ethernet or WiFi radio channel. Since there could be multiple mobile hosts receiving broadcast data within the broadcast area of a broadcast station, the multiple broadcast data receivers connected to the network can receive broadcast data from the broadcast data server at the same time.

In this research, we set up our target vehicular application as an off-board car navigation system receiving geographic road map data through a wireless broadcast channel. The broadcast data server broadcasts map data items and the broadcast data receiver in the mobile host receives some of the map data items that the mobile host requires. The criteria by which the mobile host selects the data items are mobile host's mobility specifications, which we will describe later.

3.2.1 Broadcast Data Server

The broadcast data server contains location-aware information in the broadcast data storage. The broadcast transmitter reads data items from the data storage, packetizes the information to broadcast the data items, and broadcasts data to the network that adopts a broadcast program. When broadcasting information, the broadcast transmitter activates functions regarding the packet size, the broadcast period, and the selection of data items for the broadcast program. The broadcast transmitter transmits data items without any request from any broadcast data receiver.

Data delivery through broadcasting is implemented as a datagram broadcast with UDP (User Datagram Protocol) as a transport layer protocol over an IP (Internet Protocol) net-

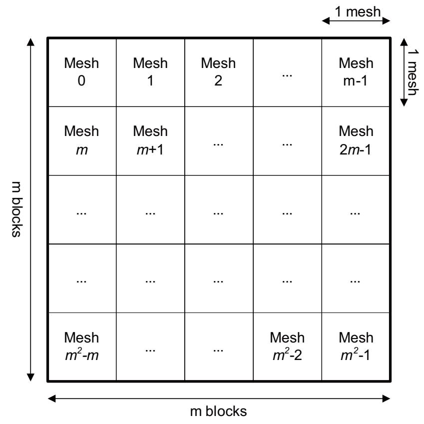

Figure 3: Map data tiles with $m \times m$ mesh boundaries

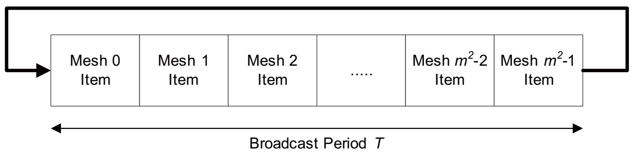

Figure 4: Broadcast data cycle

work. UDP provides no guarantees to the broadcast transmitter application for data item delivery and the broadcast transmitter retains no state on the UDP datagrams once sent.

When broadcasting geographic road map data is tiled with $m \times m$ mesh boundaries, as shown in Figure 3, a broadcast data receiver can access specific items from the broadcast data; in this case, the map data items that relate to the current location of the mobile host. The access time is the average time that elapses from the moment a mobile host requires certain data items to the receipt of these items on the broadcast channel. The broadcast data should be organized so that access time is minimized. Under a general broadcasting mechanism, it is impossible to take into account all broadcast data items required by all mobile hosts.

In this research, we adopt the simplest way to organize the transmission of broadcast data, which we call flat organization. There is no priority of any of the square-meshed map data items. The broadcast program is arranged as a flat data carousel as shown in Figure 4. The square-meshed map data items are broadcast in the following order: Mesh 0, Mesh 1, Mesh 2, $\cdots$ and Mesh $m^2 - 1$.The mesh 0 item is broadcast again after the Mesh $m^2 - 1$ is sent.

3.2.2 Broadcast Data Receiver

The broadcast data receiver described in Figure 2 in a mobile host receives the data items broadcast by the broadcast data server. It is possible that there are multiple mobile hosts within a certain broadcast area, and each mobile host receives exactly the same data from the broadcast station. The broadcast tuner in the broadcast receiver depacketizes the received data and checks for errors. The storage manager selects some of the received data items according to requests from the data selector, and stores the data items into the broadcast data cache. The location function module manages the current position, the moving direction, and the mobility specifications. The data selector receives this information and send requests to the storage manager about which broadcast data items need to be kept in the cache, using the caching algorithm described in the next subsection. The broadcast data items that a mobile host does not need are not stored in the cache; however, another mobile host may require these data items.

The storage manager provides the display manager with data items from the broadcast data cache. The display manager has information about which data items are required at a certain time, and sends these data items to the display; geographic road map images then appear on the display. Unnecessary data items kept in the broadcast data are purged by the storage manager in response to requests from the data selector that relate to mobility specifications.

3.3 Caching Algorithm

3.3.1 Mobility Specifications

Mobility specifications are composed of the current location, the destination location, the link (road) list during the time a mobile host moves from the current location to the destination, and the time data when a mobile host passes through nodes and links. We assume a mobile host can measure its current location, the current time, the direction in which it is moving, and its mobility specifications by acquiring inputs from the following functions: a GPS receiver; geographic road network data stored on a CD/DVD-ROM or hard disk drive; a speed meter; an angular velocity sensor; and a route calculation program that automatically calculates the shortest travel time route from the vehicle's current location to the desired destination.

Mobility specification data is generated using the route calculation program. Users can also individually set a desired route that need not be the route with the shortest travel time. We assume that a mobile host moves according to the mobility specifications previously set by the route calculation program or individual users.

3.3.2 Caching Mechanism

The concept of scope is useful for deciding the timing of the data to be prefetched and replaced in a mobile host's cache. In the case of geographic road map data, the scope of small-scale (wide area) map data is defined as large and the scope of large-scale (detailed) map data is small.

Suppose that a mobile host tries to make use of data items and that are not stored in the cache; mobile hosts need to wait for the data items to appear on the channel. Generally, mobile hosts need to wait an average of half a broadcast period to receive a specific data item. To eliminate waiting time, prefetching on a cache is preferable for mobile hosts. Because

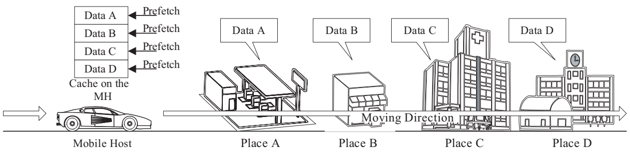

Figure 5: Prefetching of location-aware data

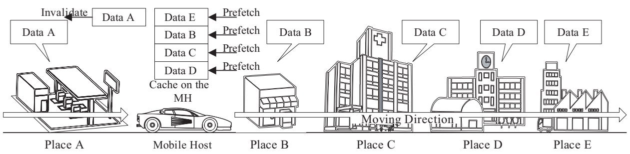

Figure 6: Replacement of location-aware data

of a mobile host's memory size limitations, useless data must be replaced in order to receive new data.

3.3.3 Prefetching Policy

As shown in Figure 5, the mobile host moves in the direction of the arrow and stores the location-aware information A, B, C, and D regarding facilities located at A to D, which are all further along the mobile host's route. In this example, the mobile host is supposedly implemented with a cache for four sizes of data items. In this case, the size of each data item is the same. With the prefetching policy, the mobile host stores the data items in the cache when the mobile host approaches a particular place and that location enters the scope of the data. Moreover, in a case where the cache is not full of data items, the mobile host can prefetch further data items relating to places further along their route, even though the mobile host is not in the scope of the other data. The mobile host does not cache data items that are not located on routes that follow the mobility specification of the mobile host.

When prefetching data items in the cache, mobile hosts do not need to wait until the data items arrive at the mobile hosts. With push-based delivery, the mobile host stores the required data items that appear on the channel, before they use the data. With pull-based delivery, the mobile host automatically sends a request to receive data at a certain location where it enters the scope of data items. Besides the facility data shown in this example, this mechanism is also useful for caching geographic road map data.

3.3.4 Replacement policy

The replacement policy is explained in Figure 6. Suppose the mobile host continues to move and pass through place A after the mobile host prefetches data relating to places A to D. When the mobile host approaches place E and that place enters the scope of the data, the mobile host tries to prefetch data E. In this situation, since the cache has no space for data E, one of data items A to D needs to be replaced to store the new data. We assume there is little chance that the driver will make a U-turn and that the mobile host will want to access data A after it passes through place A. Therefore, with the replacement policy, data A is replaced because the mobile host has already passed through it and it exits the scope, when approaching place E.

This is known as the LRU replacement policy, in which the data that has been unused for the longest time is replaced. This is effective in a general cache system. However, we believe that the LRU policy is not effective for accessing location-aware information. In Figure 5, data A, B, C, and D are stored in the cache in that order because the mobile host approaches the places in the same order. In addition, when the mobile host passes through place A, the mobile host accesses data A. Therefore, if the LRU policy is adopted, data B is supposed to be replaced because data B is not accessed for the longest period among the data A to D, although there is a good possibility that the data B will be accessed next. When the mobile host arrives at the place B, it restores data B using either push-based or pull-based delivery. This situation is very ineffective.

With this policy, the cache data is replaced more effectively compared with the LRU in the case of location-aware information, because the cache system checks the moving direction of the mobile host and the location and scope of each data item.

3.4 Broadcast Data Selection

Selection of the map data items depends on the mobile host's mobility specification (current location, moving speed, moving direction, and so on). For simplicity, we adopt a simple mobility specification to obtain square-meshed geographic map data. As the mobile host moves, the selected map data items change. Suppose the mobile host has already stored map data items around its current location, and the mobile host then requires map data items for the location it is currently moving towards. The mobile host needs to predict its future location using mobility specification, and select and store the map data items around the new location from the broadcast data before the mobile host arrives at the location. In addition, the map data items for the backward area of the mobile host will be purged from the cache.

In our system, the faster a mobile host moves, the larger the map data area is stored in the cache, to diminish the risk of no data items being stored around the new current location. Examples of map data item selection are illustrated in Figures 7 and 8. Figure 7 shows the cache area in a case where the vehicle speed is $v = l/T$, the mesh size of the map data is $l \times l$, and broadcast period is T.

Suppose a location coordinate of the current mobile host's position is (0,0), the data items (-1,1), (0,1), (1,1), (-1,0), (0,0), (1,0), (-1,-1), (0,-1), and (1,-1) are stored while the mobile host moves at the vehicle speed $v = l/T$. When the mobile host moves from (0,0) to (0,1) according to the mobile specification, the data items (-1,-1), (0,-1), and (1,-1) would not be necessary, while (-1,2), (0,2), and (1,2) need to be stored. When the mobile host moves to (-1,1) according

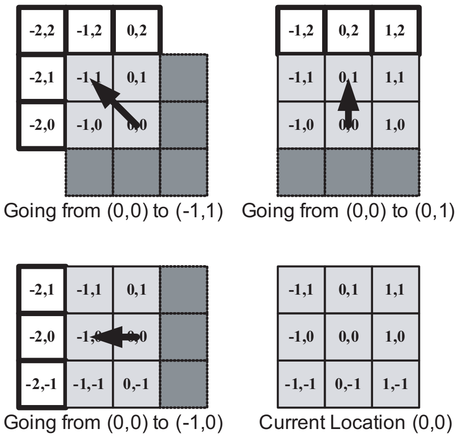

Figure 7: Data cache area ($v \simeq l/T$)

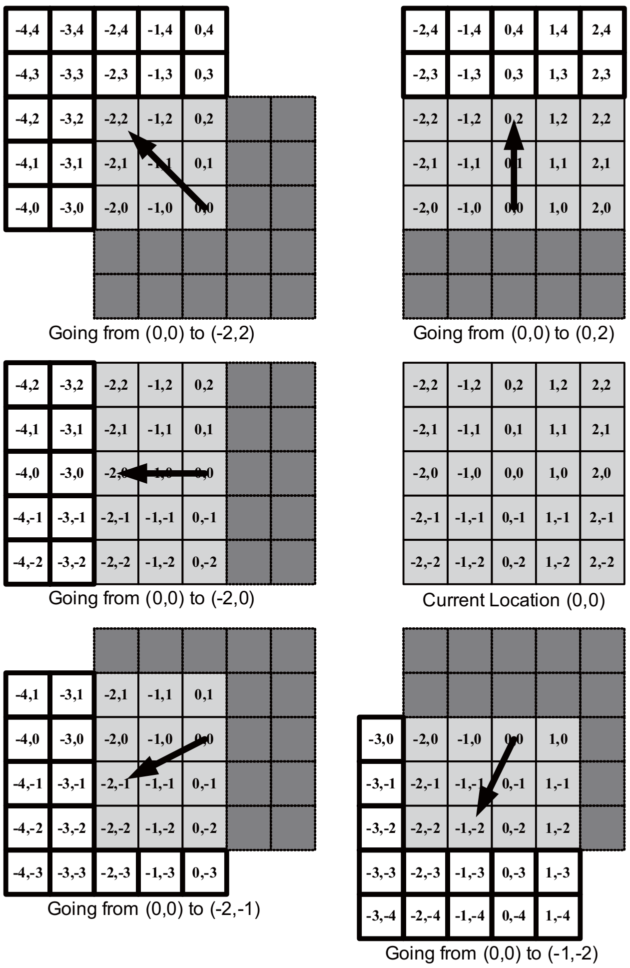

Figure 8: Data cache area ($v \simeq 2l/T$)

Table 1: Emulation parameters

Emulation Item	Parameter
Packet size	2kBytes
Data transmit interval	100ms
Valid bit rate	160kbps
Mesh size of the map	2km mesh (2km × 2km area)
Broadcast area	14km × 14km (49 meshes)
Data size per mesh	25kByte - 50kByte
Broadcast cycle	approx. 100s
Cache size	9, 25, 49 meshes

to the mobile specification, the data items (1,1), (1,0), and (-1,-1), (0,-1), and (1,-1) are not necessary, while (-2,2), (-1,2), and (0,2), (-2,1), (-2,0) need to be stored. In this case, the vehicle speed should be $v = \sqrt{2}l/T$. Figure 8 shows the cache area of the map data when the vehicle speed is $v = 2l/T$.

4 DATA BROADCAST EXPERIMENT

4.1 Broadcast Map Data

We performed a data broadcast experiment with our implemented system to emulate a location-aware information delivery method for a vehicular application using data broadcast. A broadcast data server PC used as broadcast station, and multiple broadcast data receiver PCs used as mobile hosts are connected to the IP network described in Section 3.2. The parameters of data broadcast under this experiment are shown in Table 1.

In a case where the packet size is 2kBytes and the data transmit interval is 100ms, the valid bit rate for data transmission becomes 160kbps (approximate half as effective as of 312kbps). Because the IP network bit rate (more than a megabit per second) is much faster than the one-segment digital terrestrial broadcasting bit rate (about hundred kilobits per second), a certain transmit interval is set between the broadcast data. The mesh size of the map data used in this experiment is level 2, which we call the L2 mesh; a single L2 mesh of the map data covers (2km × 2km). When the map area is a 49 (7 × 7) meshed map, the broadcast period becomes approximate 100s, and the total broadcast area is 14km × 14km.

4.2 Map Display

Figure 9 shows an example of an emulation model display. The meshed map data items are broadcast from the broadcast data server to multiple mobile hosts, and the mobile host receives the map data items it needs. To achieve a location-aware information delivery method for a vehicular application with digital broadcasting, we implemented the map display function of a car navigation system and a mobile host's location emulation program on a PC. The current location of the mobile host is shown as a center small circle on the map, which is a vehicle locator mark. As the mark moves along the pre-recorded route stored as a PC data, the broadcast data receiver application receives meshed map data relating to the direction in which the vehicle is moving. The data items for

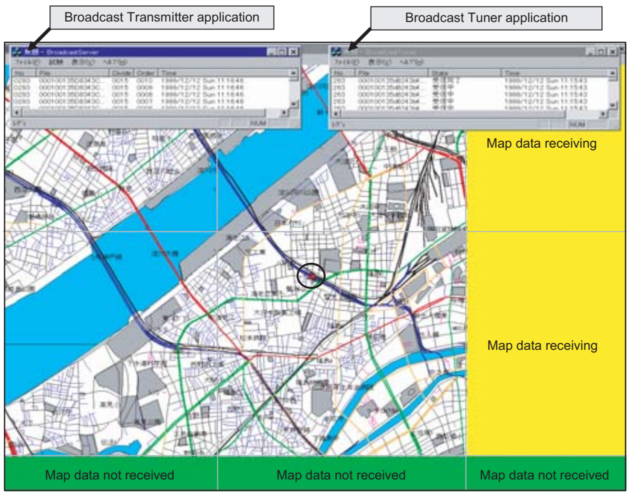

Figure 9: Simulation for data broadcast

the areas that are shown as dark colored parts of the meshed data inside the display (at the bottom of the figure) have not yet been received, and the data items for the areas that are shown as more brightly colored parts (right of the figure) are in the process of being received, which means these parts of the map appear shortly.

4.3 Evaluation

When average vehicle speed of the mobile host was 70km/h ($v \simeq l/T$), the packet size was 2kBytes, and the data transmit interval was 100ms, we confirmed there was no delay in displaying the appropriate map data following the mobile host's movement. We also confirmed there was no delay when the average vehicle speed of the mobile host was 140km/h ($v = 2l/T$) where the size of the cache is 1.25MBytes (50kBytes $\times$ 25 meshes).

Using numerical evaluation without considering mobility specification, the required broadcast bit rate would be approximate 16.7Mbps, if there was no cache in the mobile host, where broadcast area of a certain digital terrestrial broadcast station is 100km $\times$ 100km, and maximum vehicle speed is 120km/h. Because the real available broadcast bit rate is 160k bps, the required cache size is 5MBytes. The required cache size depends on the broadcast area and the maximum supported vehicle speed.

5 CONCLUSION AND FUTURE WORK

The one-segment digital terrestrial broadcasting service began in Japan in 2006. Current navigation systems generally provide drivers with information through cellular phone networks; however the one-segment broadcast is an additional candidate for disseminating location-aware information to vehicular applications.

In order to deliver location-aware information to a vehicle through broadcast channels, we proposed a new cache system to effectively prefetch and replace cached data using mobility specifications, which is a schedule according to the direction in which a mobile host moves. In this paper, we implemented an emulation system to evaluate our location-aware information delivery method using a cache system for a concrete vehicular application, which delivers geographic road map data to a car navigation system. Through our experiments, we confirmed the method worked.

In this research we adopted an Ethernet and a WiFi radio channel as the IP network, which both have very small error rates. However, the error rate with a real digital terrestrial broadcast must be bigger than in the network we used for our experiment. Conducting an evaluation that includes error rates over the broadcast channel will be the subject of our future work.

REFERENCES

[1] ARIB STD-B31 Version 1.5, Transmission System for Digital Terrestrial Television Broadcasting, Association of Radio Industries, and Businesses, (2003).

[2] ARIB STD-B38 Version 1.3, Coding, Transmission and Storage Specification for Broadcasting System Based on Home Servers, Association of Radio Industries, and Businesses, (2006).

[3] K. Matsumura, K. Usui, K.Kai, and K. Ishikawa, Location-aware Data Broadcasting: an Application for Digital Mobile Broadcasting in Japan, Proc of ACM International Conference on Multimedia, pp. 271–274 (2003).

[4] E. Pitoura, and G. Samaras, Data Management for Mobile Computing, Kluwer Academic Publishers, pp.71–85 (1998).

[5] S. Acharya, R. Alonso, M. Franklin, and S. Zdonik, Broadcast Disks, Data Management for Asymmetric Communication Environments, Proc. of ACM SIGMOD International Conference on Management of Data, Vol.24, No.2, pp.199–210 (1995).

[6] D. Barbara, and T. Imielinski, Sleepers and workaholics, Caching Strategies in Mobile Environments, Proc. of ACM SIGMOD International Conference on Management of Data, Vol.23, No.2, pp.1–12 (1994).

[7] J. Jing, O. Bukhres, A. Elmagarmid, and R. Alonso, Bit-Sequences: A New Cache Invalidation Method in Mobile Environments, Technical Report CSD-TR-94-074, Department of Computer Science, Purdue University (1995).

[8] K. Sato, K. Saisho, and A. Fukuda, A Caching Algorithm for Location-aware Information Disseminated through Broadcast Media, IPSJ Journal, Vol. 41, No.9, pp.2434–2444 (2000).