Research Article

Broadcasted Location-Aware Data Cache for Vehicular Application

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There has been increasing interest in the exploitation of advances in information technology, for example, mobile computing and wireless communications in ITS (intelligent transport systems). Classes of applications that can benefit from such an infrastructure include traffic information, roadside businesses, weather reports, entertainment, and so on. There are several wireless communication methods currently available that can be utilized for vehicular applications, such as cellular phone networks, DSRC (dedicated short-range communication), and digital broadcasting. While a cellular phone network is relatively slow and a DSRC has a very small communication area, one-segment digital terrestrial broadcasting service was launched in Japan in 2006, high-performance digital broadcasting for mobile hosts has been available recently. However, broadcast delivery methods have the drawback that clients need to wait for the required data items to appear on the broadcast channel. In this paper, we propose a new cache system to effectively prefetch and replace broadcast data using "scope" (an available area of location-dependent data) and "mobility specification" (a schedule according to the direction in which a mobile host moves). We numerically evaluate the cache system on the model close to the traffic road environment, and implement the emulation system to evaluate this location-aware data delivery method for a concrete vehicular application that delivers geographic road map data to a car navigation system.

1. INTRODUCTION

As technologies of mobile computings and communications have become highly extensive and functional, computer systems equipped in a vehicle such as navigation systems with wireless communication have been popularized recently to contribute to improving road transportation, efficiency, and comfort. These systems generally provide drivers with traffic information, weather report, and other individualized data at the driver's request such as information on restaurants, amusement parks, landmarks, hospitals, and so forth through cellular phone networks. The wireless networks are relatively slow and unstable compared with wired communication networks.

Digital broadcasting for mobile hosts has been available recently; for example, one-segment broadcasting service [1] began in Japan on April 1, 2006. This broadcasting service for mobile hosts 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].

The broadcast services for mobile are additional candidates for disseminating location-aware data for vehicular applications. Using this broadcast method to deliver location-aware data 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.

This high performance digital broadcasting for mobile hosts has been available recently. However, broadcast delivery methods have the drawback that clients need to wait for the required data items to appear on the broadcast channel. In order to reduce the time a mobile host needs to wait, and to receive and store data effectively on the mobile host,
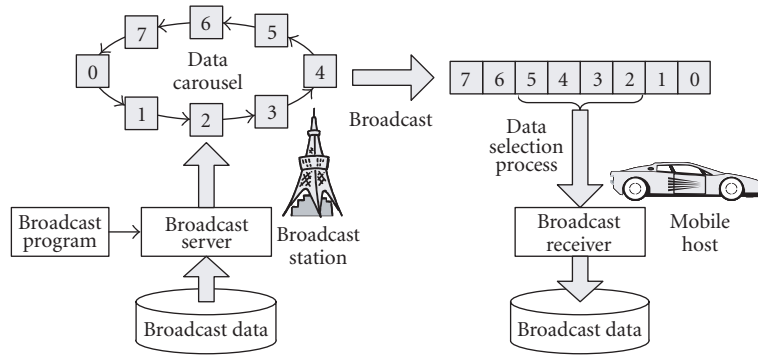
FIGURE 1: Broadcast model outline.

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 and Imielinski 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 time stamps.

In recent several years, there are many caching schemes proposed for broadcast data in mobile computing environments. Applications that employ broadcast data delivery mainly are Internet TV programs for mobile users. Chow et al. proposed a distributed group-based cooperative caching scheme [8] by capturing data affinity of individual peers and mobility patterns in a mobile broadcast environment. Ercetin and Tassiulas developed the method for joint cache management and scheduling problem [9] for satellite-terrestrial broadcasting. In their two-stage broadcast data delivery system, a main server broadcasts information to local stations and the local stations act as intermediate stages and transfer information to mobile users. Birk and Tol presented ISCOD approach [10] from a server to multiple caching clients over a broadcast channel. This method is based on high-speed forward broadcast channel and a slow reverse channel. These approaches are not effective for location-aware data dissemination without uplink methods in specific mobile computing environments (e.g., car navigation systems).

In this paper, we propose a cache system to reduce the waiting time specially for location-aware data. With the cache system, a data item is prefetched and replaced at an appropriate timing according to the mobility specification. We numerically evaluate the cache system on the model close to

the traffic road environment, and implement the emulation system to evaluate this location-aware data delivery method for a concrete vehicular application that delivers geographic road map data to a car navigation system.

We believe that the methods described above are not always effective for receiving location-aware data on a mobile host and that there could be more effective caching methods for a vehicular application. We propose a cache system especially for caching location-aware data 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; a schedule that a mobile host is expected to travel.

2. BROADCAST DATA MANAGEMENT

2.1. Broadcast scheme

There are two kinds of methods to deliver data to mobile hosts through wireless communication; one is push based and the other is pull based. In pull-based data delivery, a mobile host can explicitly request specific data items to the information center. The limitation of this pull-based data delivery is not scalable; each mobile host allocates its own communication channel to the information center. In push-based data delivery, data are repetitively broadcasted to a mobile host population having no specific request. Mobile hosts monitor the broadcast and retrieve the data items they are interested in when the data items appear on the broadcast channel. Push-based data delivery is suitable in cases in which information is transmitted to a large number of mobile hosts with overlapping interests, because this delivery is scalable and the performance does not depend on the number of mobile hosts listening to the broadcast. However, one of the limitations is that access is only sequential; mobile hosts must wait until the required data items appear on the channel.

Figure 1 shows the outline of data dissemination from a broadcast station to a mobile host. The broadcast data items are location-aware data 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
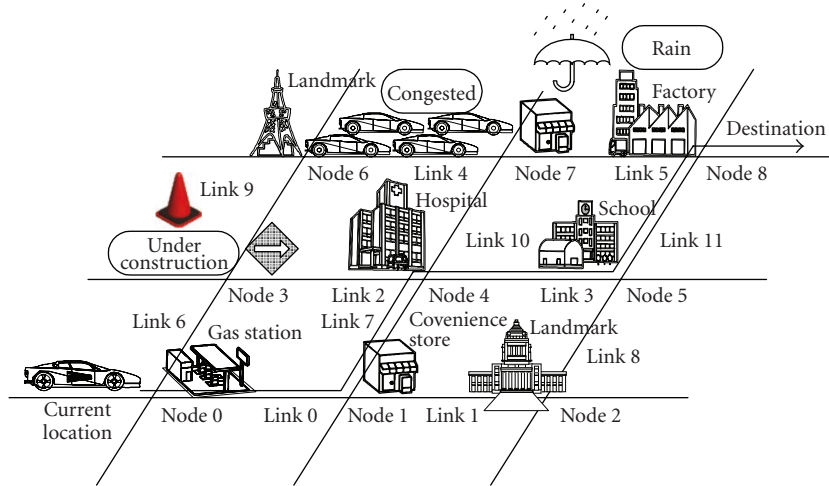
FIGURE 2: Example of location-aware data.

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.

2.2. Digital terrestrial broadcast for mobile host

The digital terrestrial broadcasting system in Japan applies ISDB-T (integrated services digital broadcasting-terrestrial) 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 (6 MHz 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 312 kbps with DQPSK modulation and 1/2 inner convolution error correction, 416 kbps with DQPSK modulation, and 2/3 inner convolution error correction, 624 kbps with 16 QAM modulation, and 1.4 Mbps with 64 QAM modulation. Since the ISDB-T specification includes a data broadcasting function, we believe that the ser-

vice would be applicable for delivering location-aware data to vehicular applications.

3. LOCATION-AWARE DATA DELIVERY

3.1. Location-aware data

We refer to location-aware data as information regarding hospitals, gas stations, landmarks, and so forth which shown in Figure 2 are usually managed on mobile hosts. The location-aware data are basically dependent on geographic locations. Therefore, traffic information and weather reports are also included in the category. Moreover, we also define a scope of location dependent data as the available area of the data. For example, the scope of traffic information or weather reports is the area where the information or the report is referred.

Figure 3 shows that the convenience stores at the places B and F have a narrow scope, while the hospital at the place C has a wider scope. Some traffic information generally still have larger scope. Weather reports have an even wider scope for each information. Data are supposed to be available on a mobile host in the case it is located within the scope of the data, otherwise data are not available when it is not within the scope. The idea of the scope is useful to decide the timing when the data is prefetched and replaced in a cache on a mobile host.

3.2. Mobility specification

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
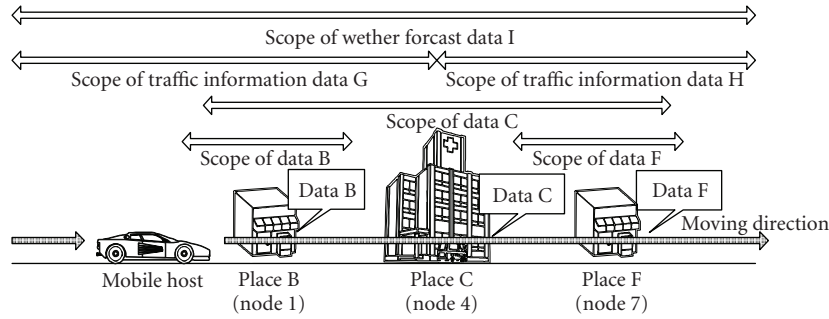
Figure 3: Scope of location-aware data.

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.

4. CACHING ALGORITHM

4.1. Caching mechanism

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

We consider the case that a mobile host moves in the direction of the arrow on the road network shown in Figure 2. There exist the location-aware data on the road network, and the mobile host is supposed to use the data item regarding each place on the road. In this situation, the caching and replacement policy in this paper is explained in the following. We use the simple straight route for the explanation, although the route of the mobile host in Figure 2 is not straight. Figure 4 shows the procedure of caching data items.

4.1.1. Prefetching policy

As shown in Figure 5, the mobile host moves in the direction of the arrow and stores the location-aware data A, B, C, and D regarding facilities located at A to D, which are all further
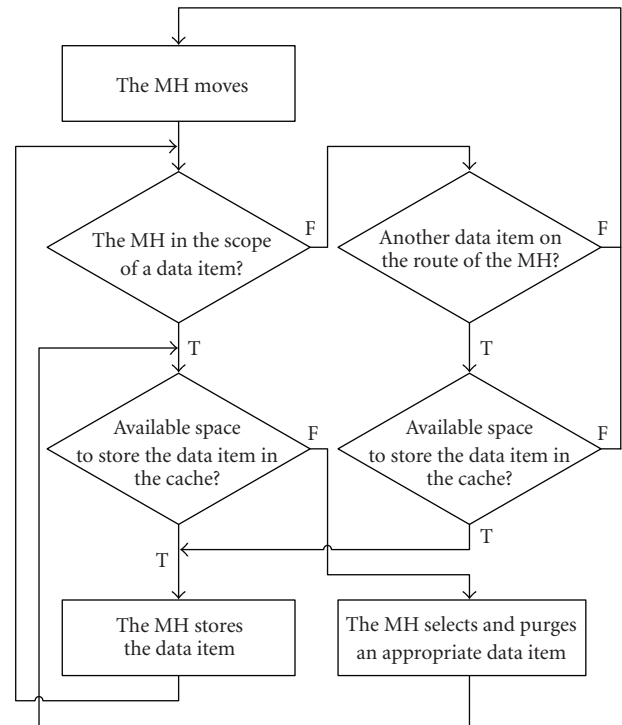

Figure 4: Procedure of caching data items.

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
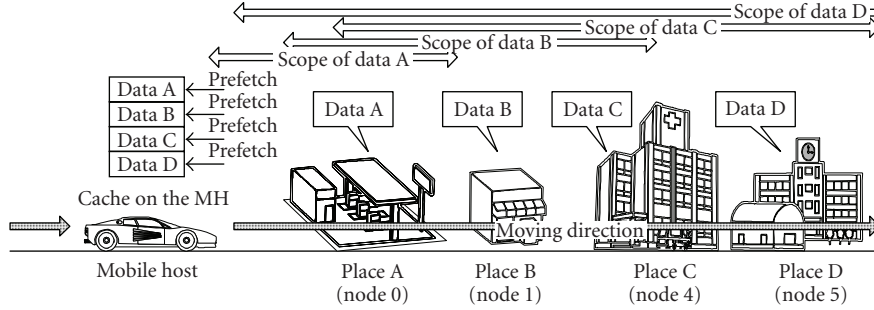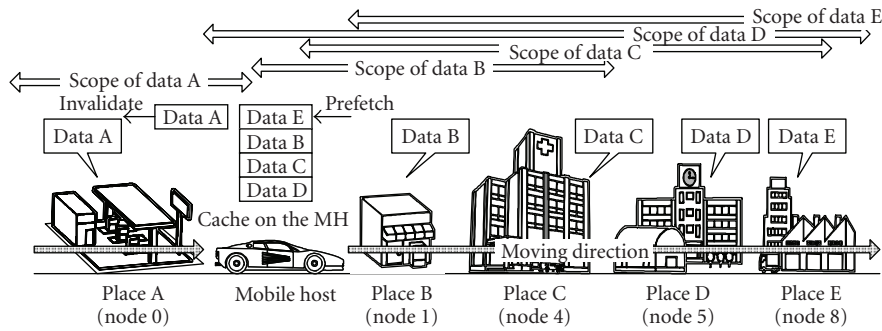
FIGURE 5: Prefetching of location-aware data.

FIGURE 6: Replacement of location-aware data.

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.

4.1.2. 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.

It is known that the LRU (least recently used) replacement policy, with which the data replaced is the one that has been unused for the longest time, is effective in a general cache system. However, we believe that the LRU policy is not effective for accessing location-aware data. 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 data, because the cache system checks the moving direction of the mobile host and the location and scope of each data item.

5. EVALUATION OF THE CACHE SYSTEM

5.1. Evaluation method

To simply evaluate the cache system, we use a mathematical method to measure the total of miss penalty for which each client has to wait until the required data appear on the channel. If the required data is already prefetched and stored in the cache, the penalty time is estimated at zero. Generally prefetching schemes are limited both by prediction accuracy and by the penalty for misprediction. The former depends on a selection method of prefetching items and the size of the cache, and the latter is the time elapsed from the moment

Node 0 item	Node 1 item	Node 2 item	. . .	Node $m^2 - 2$ item	Node $m^2 - 1$ item

$$\longleftarrow \qquad \text{Broadcast period } 1/f(T) \qquad \longrightarrow$$
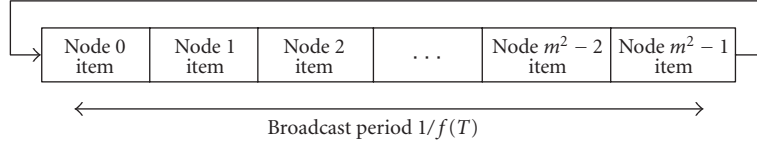
FIGURE 7: Broadcast method (flat organization).

a client expresses its interest to an item to the appearance of the item on the broadcast channel. Therefore, we adopt caching methods and cache size as evaluation parameters.

5.2. Evaluation model

The road network model shown in Figure 2 is used to evaluate the cache performance of the three kinds of cache model corresponding to the information of a mobile host: (1) random data cache to prefetch data items at random in the cache, (2) neighbor data cache to prefetch data items, which are location-aware data, around the current location of the mobile hosts, and (3) routed data cache to prefetch data items on the route that the mobile host is expected to follow. In the case that the location of a mobile host is unknown, the random data cache is used, and in the case that only the location of a mobile host is known, the neighbor data cache is used. The routed data cache proposed in this research is used when the location and the route of a mobile host are known by mobility specification. The evaluation includes the following conditions.

(1) The road network model is composed of simply meshed m nodes $\times$ m nodes. Each node is located at the same distance; each link is the same length l.

(2) A mobile host enters the road network from the corner of the network; that is the start point. The goal of a mobile host is a cater corner to the start point. Speed of a mobile host, v, is the same from the start point to the destination. A mobile host makes a random choice of one of the shortest routes from the start point to the goal.

(3) A data item related to each node in the road network, that is a location-aware data, is broadcasted with a flat organization shown in Figure 7. The size of each data item S_{data} is the same, and the frequency of the broadcast is f. The average of the period of time that an interesting item appears on the broadcast channel is $1/(2f)$. The client interests the data items on the route which the mobile host follows.

(4) A client prefetches data items on its cache. The size of the cache is S_{cache}. Since the cache replacement policy is described before, we assume the replacement policy of cached data is optimal in this evaluation.

5.3. Evaluation result

We evaluate the average of miss penalty for each method, P_{random}, P_{neighbor}, and P_{routed} for the three cache policies: (1)

random data cache, (2) neighbor data cache, and (3) routed data cache. The average of miss penalty when the data is not in the cache is $1/(2f)$. The number of nodes when a mobile host passes from the current location to the destination is $2m - 2$, where the client takes each location-aware data. The speed of a mobile host, v, is shown by nfl, where n is the number of links through which a mobile host passes for a unit period of time.

The average of total miss penalty for each cache policy is the product of the probability to miss the cache for each method, the average of miss penalty $(1/2f)$, and the number of nodes that a mobile host pass through $(2m - n)$,

$$P_{\text{random}} = \frac{(m^2 - s)^+}{m^2} \cdot \frac{1}{2f} \cdot (2m - 2),$$

$$P_{\text{neighbor}} = \frac{\left(\left(1 + 4 \sum_{i=1}^{n} i \right) - s \right)^+}{1 + 4 \sum_{i=1}^{n} i} \cdot \frac{1}{2f} \cdot (2m - 2), \qquad (1)$$

$$P_{\text{routed}} = \frac{(n - s)^+}{n} \cdot \frac{1}{2f} \cdot (2m - 2),$$

where a^+ is $\max(a, 0)$, s is $S_{\text{cache}}/S_{\text{data}}$, and n is flv; the larger n is, the faster the mobile host moves. The case of the neighbor data cache is approximate value under the condition which the value of m is much large compared with the value of n. The evaluation result for the three data caching policies is shown in Figures 8, 9, and 10, in the condition that $m = 50$, $f = 0.5$, and $n = 1$, $n = 3$ and $n = 5$, respectively. The routed data cache we propose has much smaller penalty with a small size of cache in comparison with the random data cache and the neighbor data cache.

5.4. Emulation system

To study location-aware data delivery method using data broadcasting, we implemented the emulation model shown in Figure 11. 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.
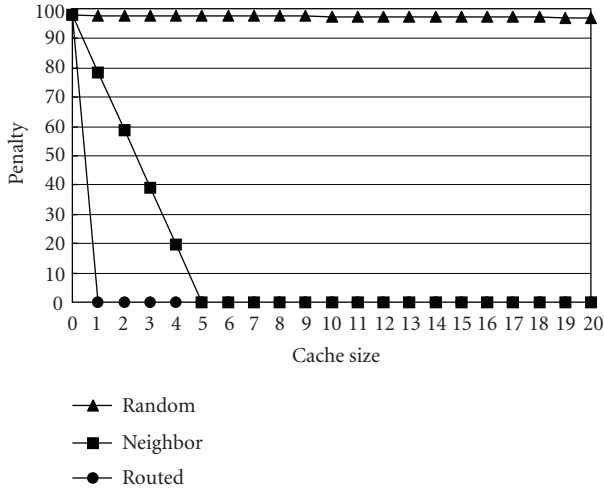
FIGURE 8: Penalty of cache method ($n = 1$).
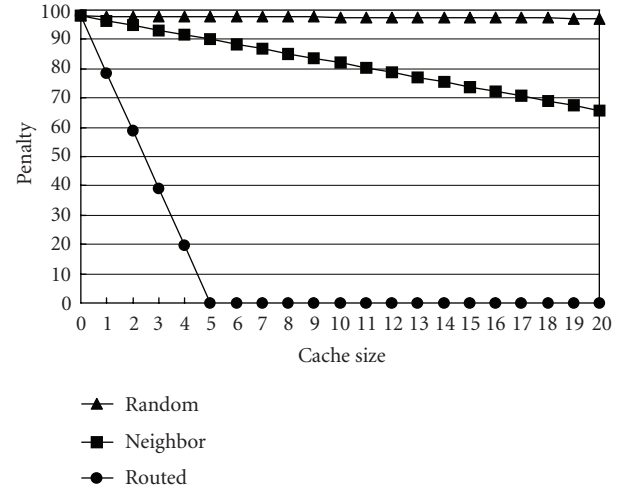
FIGURE 10: Penalty of cache method ($n = 5$).
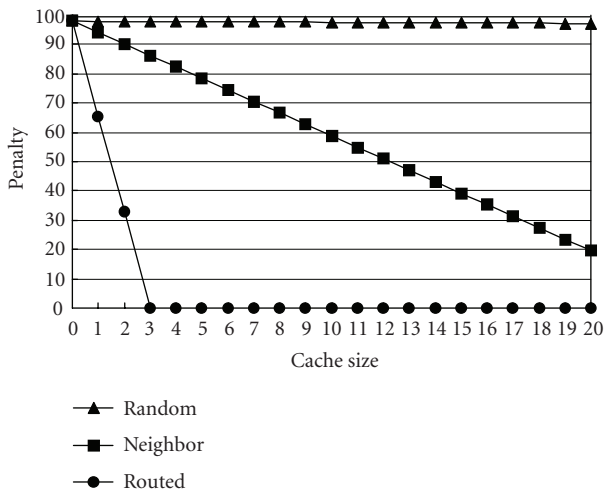
FIGURE 9: Penalty of cache method ($n = 3$).

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.

5.4.1. Broadcast data server

The broadcast data server contains location-aware data 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 trans-

mitter 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) network. 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 12, 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 7. The square-meshed map data items are broadcast in the following order: mesh 0, mesh 1, mesh 2, . . . , and mesh $m^2 - 1$. The mesh 0 item is broadcast again after the mesh $m^2 - 1$ is sent.

5.4.2. Broadcast data receiver

The broadcast data receiver described in Figure 11 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
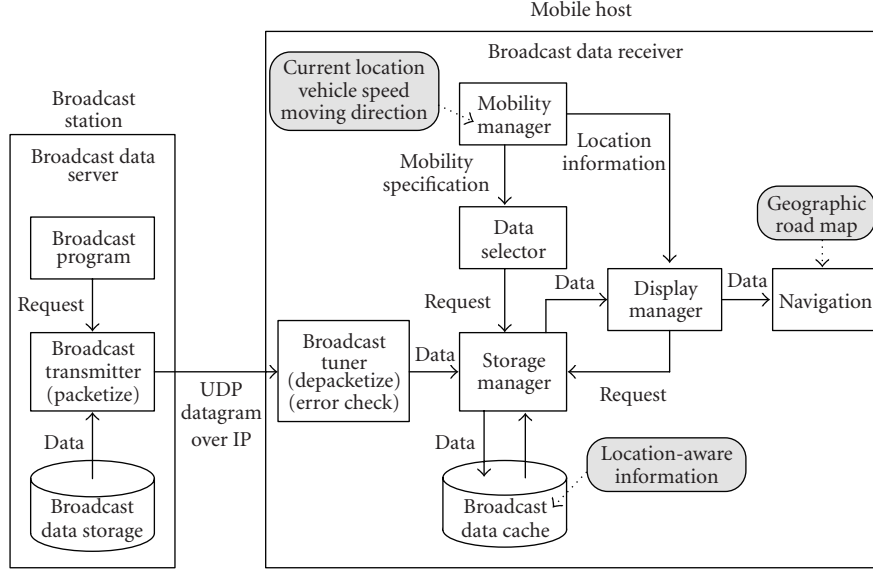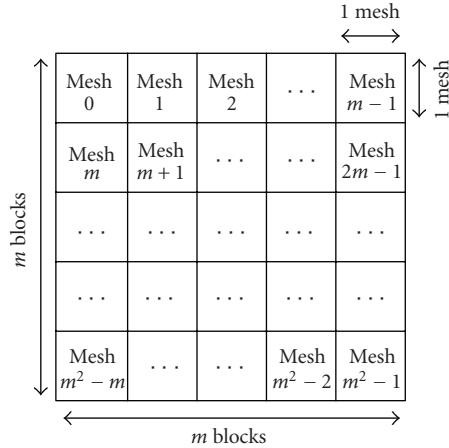
Mobile host

FIGURE 11: Emulation model for data transfer.

FIGURE 12: Map data tiles with $m \times m$ mesh boundaries.

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 sends 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. Un-
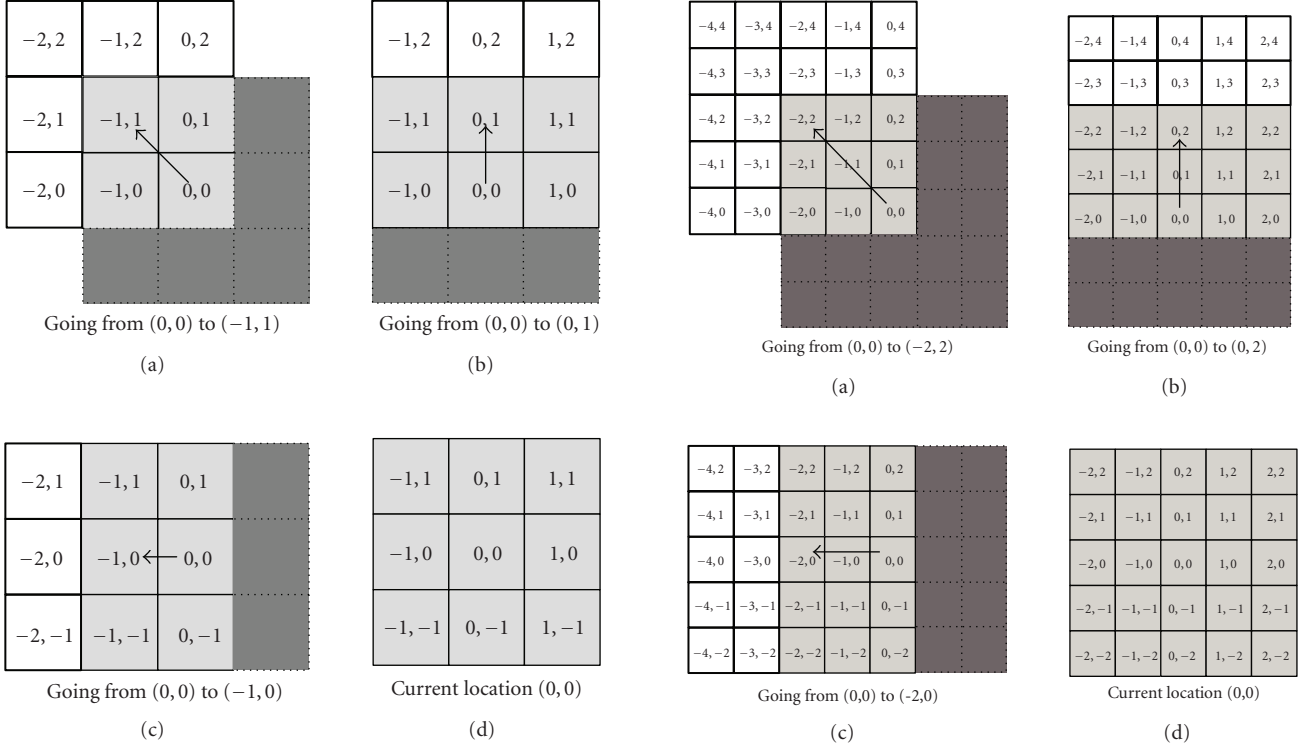
necessary data items kept in the broadcast data are purged by the storage manager in response to requests from the data selector that relates to mobility specifications.

5.5. 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 13 and 14. Figure 13 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)

Going from (0, 0) to (−1, 1)

(a)

Going from (0, 0) to (0, 1)

(b)

Going from (0, 0) to (−1, 0)

(c)

Current location (0, 0)

(d)

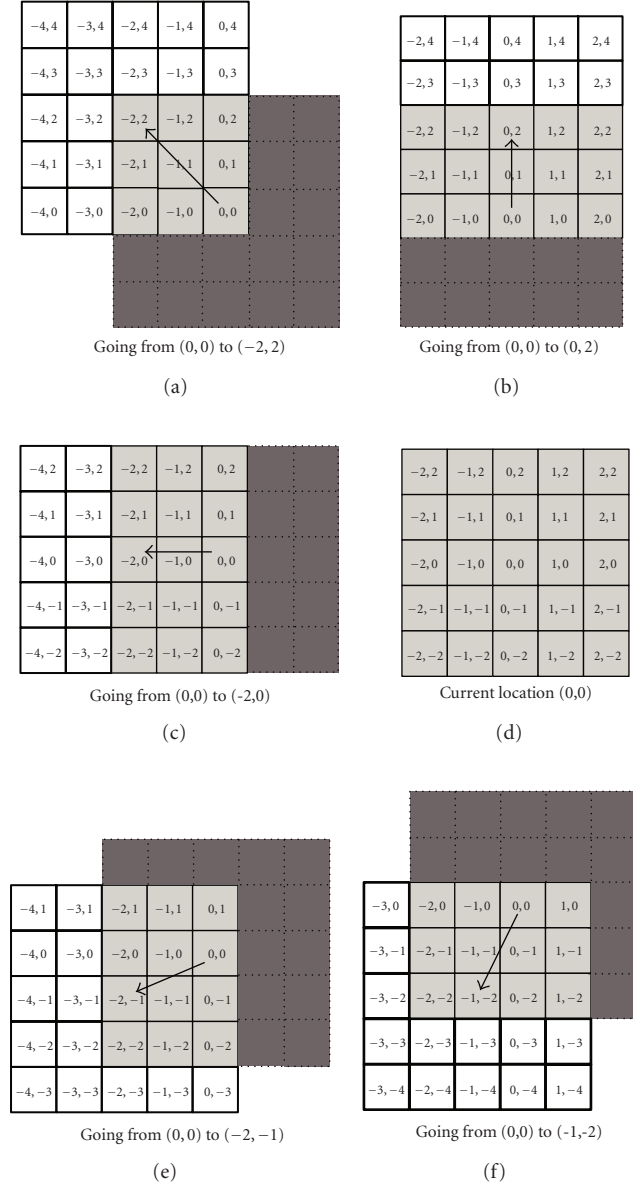Figure 13: Data cache area ($v \simeq l/T$).

need to be stored. When the mobile host moves to $(-1, 1)$ according 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 14 shows the cache area of the map data when the vehicle speed is $v = 2l/T$.

6. DATA BROADCAST EXPERIMENT

6.1. Broadcast map data

We performed a data broadcast experiment with our implemented system to emulate a location-aware data 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 5.4. The parameters of data broadcast under this experiment are shown in Table 1.

In a case where the packet size is 2 kBytes and the data transmit interval is 100 milliseconds, the valid bit rate for data transmission becomes 160 kbps (approximate half as effective as of 312 kbps). 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 (2 km × 2 km). When the

Going from (0, 0) to (−2, 2)

(a)

Going from (0, 0) to (0, 2)

(b)

Going from (0, 0) to (-2, 0)

(c)

Current location (0,0)

(d)

Going from (0, 0) to (−2, −1)

(e)

Going from (0, 0) to (-1,-2)

(f)

Figure 14: Data cache area ($v \simeq 2l/T$).

map area is a 49 (7 × 7) meshed map, the broadcast period becomes approximately 100 seconds, and the total broadcast area is 14 km × 14 km.

6.2. Map display

Figure 15 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 data 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
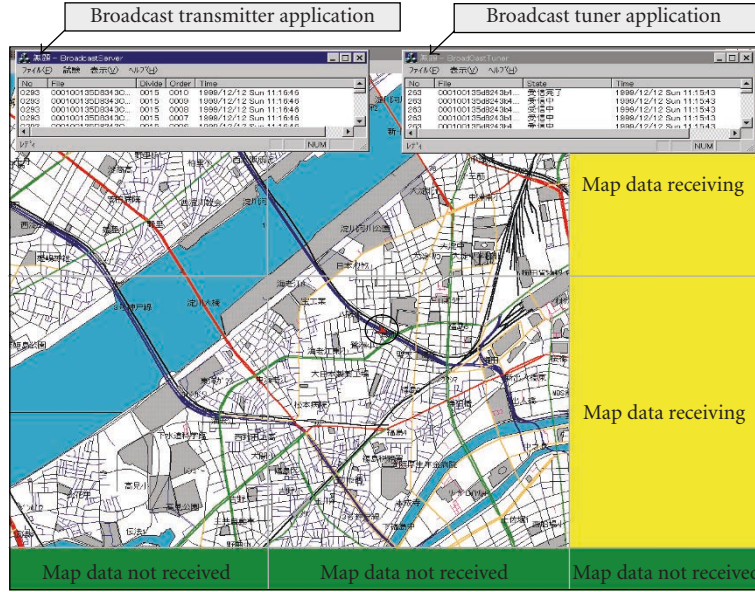
FIGURE 15: Simulation for data broadcast.

TABLE 1: Emulation parameters

Emulation item	Parameter
Packet size	2 kbytes
Data transmit interval	100 milliseconds
Valid bit rate	160 kbps
Mesh size of the map	2 km mesh (2 km × 2 km area)
Broadcast area	14 km × 14 km (49 meshes)
Data size per mesh	25 kbyte–50 kbyte
Broadcast cycle	Approx. 100 seconds
Cache size	9, 25, 49 meshes

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 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 that these parts of the map appear shortly.

6.3. Evaluation

When average vehicle speed of the mobile host was 70 km/h ($v \simeq l/T$), the packet size was 2 kBytes, and the data transmit interval was 100 milliseconds, 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 140 km/h ($v = 2l/T$) where the size of the cache is 1.25 MBytes (50 kBytes × 25 meshes).

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

7. CONCLUSION AND FUTURE WORK

These systems equipped in a vehicle can provide drivers with point-of-interest information, traffic information, weather reports and so on as well as driving directions through relatively slow and expensive cellular phone networks. Meanwhile high performance digital broadcasting for mobile hosts has been available recently.

In order to deliver location-aware data 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 data 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 that 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.

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