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Context-Aware Information Delivery Using ITS Spot Identification and Smartphones

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Improvement of information delivery systems in ITS is an important issue to provide more effective guidance and support to the drivers and passengers, and use of contextual information with improved granularity is beneficial to this end. The goal of our study is to provide a flexible information delivery system concept that makes use of various contextual data around the users to determine target receivers of the information specific to a certain context. This paper focuses on an information delivery system concept that uses finer-grained location-based screening of target receivers by integrated use of ITS spots and the Geo-messaging enabler in cellular networks. The system takes information of user's transport mode (e.g., riding on a car, walking) as a part of user's contextual information by utilizing smartphone sensors. In this paper, we present the two solution architecture alternatives that we propose to fulfill the target system functionalities and the results of the verification experiment conducted by using a prototype system of the architecture.

1. Introduction

As the ITS technology evolves, more and more information about the traffic situations can be obtained and generated. ITS dedicated wireless network systems have been developed to support V2R communications. For example, in Japan, the ITS spot infrastructure based on the DSRC standard on 5.8GHz band has been deployed nationwide on the highways, and the V2R communications for obtaining the information from the cars and delivering traffic information to the cars are supported by using the DSRC-enabled OBU (On-Board-Unit) in the cars.

In parallel, cellular mobile networks are also evolving rapidly. Mobile broadband systems based on 3GPP HSPA and LTE standards are already deployed globally and provide mobile connectivity with high bandwidth and low latency. Smartphones which take advantage of the mobile broadband are rapidly penetrating in the global market. Total smartphone subscriptions reached around 700 million in 2011 and are expected to reach around 3 billion in 2017 [8]. Smartphones are expected to be used in various information services for supporting smart mobility and also as a device to obtain various contextual data utilizing embedded sensors like GPS and accelerometer. Road Hazard Warning is an example application of the smart mobility. The CoCar/CoCarX projects studied applicability of the cellular mobile broadband systems for V2V communications to realize the Road Hazard Warning and similar services which require delivery of time-critical information [1].

Currently, the DSRC-based V2R communication and the cellular-based V2V communication are isolated and little studies have been made to explore effective combination of the two communication systems to create new values in terms of enhanced services delivered to the users. In this paper, we propose a system that leverages multi-access capability with the DSRC-based dedicated system and cellular mobile network and delivers information to user on highways with finer-grained location-based screening of target users by using their location and transport mode information.

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The rest of this paper is structured as follows. In section 2 we derive the requirements from the intended use case. In section 3 two solution architectures satisfying the set requirements are proposed. In section 4 and 5 a prototype system of the selected solution architecture is presented and verified by experiments. In section 6 and 7 we examine our work compared to prior works and conclude the paper.

2. Requirements

Amongst others, we will describe two use cases which we intend to support by the system we propose. The first use case is delivery of traffic information to smartphones of drivers in a narrow area. Currently traffic information is delivered via the ITS spots to the DSRC OBU. However, the number and locations of ITS spots are limited; they are deployed with 4km intervals on average in urban/suburban areas and the interval is larger in rural areas. Cellular networks that provide wide coverage can be used to deliver traffic information in a narrow area between ITS spots. A care must be taken, however, because traffic information for a highway should not be delivered to drivers traveling on an ordinary road to avoid getting them confused. By pairing a smartphone with a DSRC OBU, delivery of traffic information to smartphones becomes possible and it complements the information delivery supported through the ITS spots.

The second use case is delivery of shop information and coupons as incentives to guide drivers to a parking area for the sake of traffic control. In Fig.1 the horizontal road is a highway road and the vertical road is an ordinary road. On the highway road there is a parking area depicted as a box (designated by Area 2) at the center of the figure. From the exit of the parking area the highway road is congested.

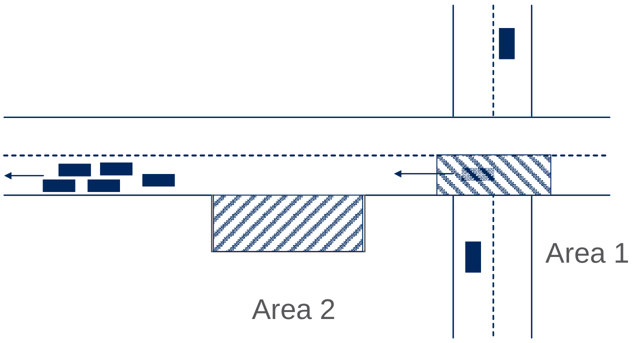


Fig.1 Use case: Message delivery to two destination areas.

The second use case is intended to give a means to attempt to lead drivers approaching to the parking area to stop by the parking area rather than going into the congestion and making the congestion situation worse. To the drivers in the parking area detailed shop information is delivered after they get off the cars. The information is presented in a way it does not grab a driver's attention to the smartphone's display while driving for safety reasons. On the other hand, drivers want to access the detailed shop information with a richer presentation after they get off their cars.

In this use case the target receivers of the messages are primarily identified by their location. Area 1 and area 2 are set as the destination area of the former and the latter information delivery respectively. A car senses its location by using GPS periodically and the messages are delivered based on the GPS location and the set destination area.

Even though the straight roads are assumed in Fig. 1 just for simplicity, real roads consist of curves and crossings with an overpass or underpass, which makes it difficult for an information provider to set a destination area in such a way that it covers only the target receivers. In case of area 1 the ordinary road under the highway is covered by the destination area even though the message should be delivered only to the cars on the highway road. In case of area 2 the destination area is set to cover the parking area. However, due to possible GPS errors there is a risk that a car traveling on the highway road from right to left receives the message sent to area 2.

Taking the above discussion into account, we set the following requirements for designing the target system.

Req.1 It shall be possible to specify one or more geographical areas as the destination of information to be delivered. Note also that the size of the destination area varies ranging from small spots to relatively wide areas.

Req.2 Information delivery shall be done in a selective manner so that right information is delivered to right users. For example, traffic information concerning a highway shall be delivered only to the cars traveling on the highway, not to the cars traveling on ordinary roads. The direction on a highway road must be distinguished.

Req.3 A driver's status of whether driving on a highway or taking a rest in a parking area must be distinguished and the information must be presented differently depending on the different situations. When driving, the information should be read aloud to avoid grabbing the driver's attention to a display. When taking a rest in a parking area, the driver may want to access the information with a feature-richer client like a web browser.

3. Solution architecture

We propose two alternatives of the solution architecture by taking the above requirements into account as depicted in Fig. 2 and 3, respectively. Each box represents a functional component and a colored box is a functional component provided as the road infrastructure. They consist of the same functional components but with different deployment. We first describe the functional components and basic mechanisms of the solutions and then discuss the advantages of each alternative.

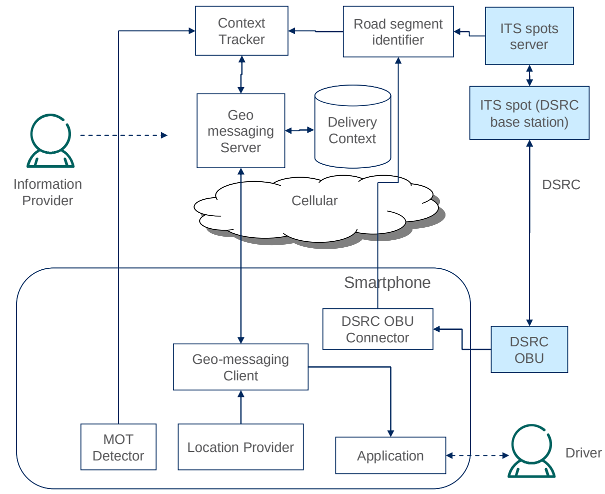


Fig. 2 Solution architecture alternative 1.

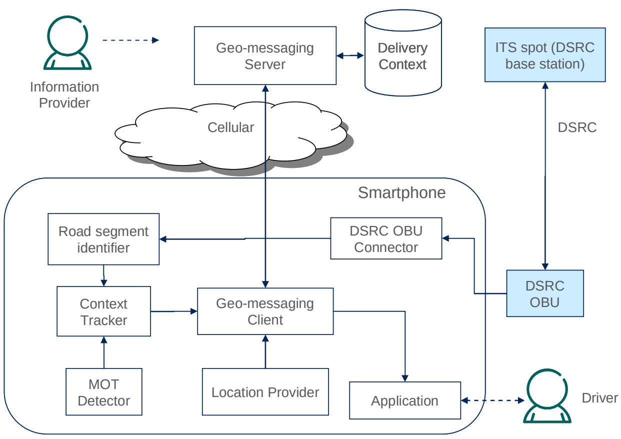


Fig. 3 Solution architecture alternative 2.

3.1 Functional components

3.1.1 Geo-messaging

Geo-messaging is the technology to delivery messages to the clients located in a certain geographical area. In our solution the Geo-messaging is used as a base technology.

A Geo-messaging client periodically registers its location to the Geo-messaging server. When a Geo-messaging server receives a message, a destination area, and delivery context, it disseminates the message to the registered Geo-messaging clients which are considered to reside in the destination area and satisfy the delivery context. The Geo-messaging server deligates to the Delivery Context Database the task of checking if a registered Geo-messaging client satisfies the delivery context. A Geo-messaging client receives messages from the Geo-messaging server. Depending on the frequency of updating the Geo-messaging server with the client's location, the client may receive a message with a destination area where the client is not included. After ensuring that the client is in the destination area the Geo-messaging client forwards the messages to the application.

3.1.2 Delivery Context Database

The Delivery Context Database takes the delivery context of a message and the actual context of a client as inputs, and returns if the client satisfies the delivery context. The delivery context includes transport modes, transition between transportation modes, and the highway road segments and directions. The Delivery Context Database aggregates the same delivery context attached to two or more Geo-messages, and assigns a Context ID to each delivery context. The Delivery Context Database provisions the Context Tracker with a state chart which generates a Context ID upon state transition.

3.1.3 Context Tracker

The Context Tracker has a state machine to keep track of actual context transition of a client. The actual context of the client is provided by the road segment identifier and the MOT detector.

3.1.4 DSRC OBU Connector

DSRC OBU receives data from an ITS spot when the car passes by an ITS spot. The data consists of at least the ITS spot identity with which the highway road and the direction can be identified. The DSRC OBU Connector in a smartphone retrieves the data from the OBU and extracts the ITS spot identity which is then passed to the Road segment identifier.

3.1.5 Road segment identifier

Based on the ITS spot identity received from the DSRC OBU Connector, the Road segment identifier looks up its database and identifies the road segment on which the car is traveling. The number of deployed ITS spots is 1,600 in year 2011 [10] and thus the internal database can be kept small enough to reside in a smartphone.

3.1.6 Mode of Transport (MOT) detector

One of the important user contexts for ITS application is the mode of transport such as walking, bicycling, standing still, taking a train, car, or bus. The Mode of Transport detector takes readings from acceleration and GPS sensors in the smartphones and optionally from external devices, and determines the user's mode of transport. It also refers to GIS information such as bus and train time tables to distinguish the transport modes which cannot be discriminated solely based on the sensor readings.

3.1.7 Location Provider

The Location Provider provides the smartphone's location by using the GPS sensor or by positioning using the WiFi or cellular network.

3.2 Basic mechanisms for capturing user's context and message delivery

Fig. 4 is a sequence diagram exemplifing interworking between the functional components in the first alternative, for the functionalties of capturing the user's context, subscribing for the Geo-messaging service for the user's context, and receiving a message delivered in the Geo-messaging service.

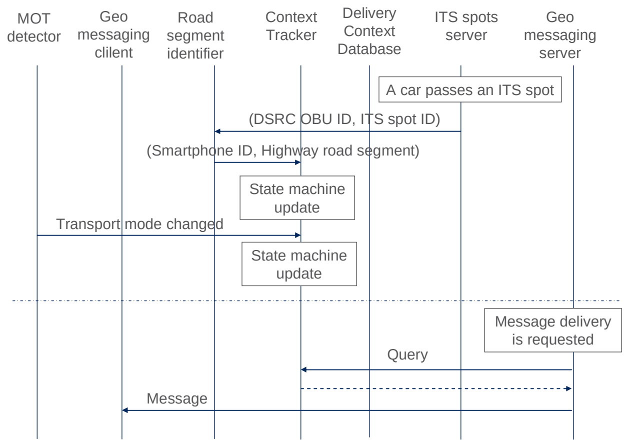


Fig. 4 Sequence diagram of alternative 1.

Before this sequence starts, it is necessary to pair the DSRC OBU identity with the smartphone identity and store the information in the Road segment identifier so that it can provide highway road segment information when asked.

When a car passes by an ITS spot, the ITS spots server notifies a pair of the DSRC OBU identity of the car and the ITS spot identity to the Road segment identifier. The Road segment identfier looks up the smartphone ID paired with the DSRC OBU identity, and also finds the highway road segment from the ITS spot ID. The Context Tracker updates the state machine for the smartphone if the state machine consists of such transition. A change detected by the MOT detector also updates the state machine in the Context Tracker. Later, when delivery of a message is requested by an information provider, the Geo-messaging server looks up the clients inside the destination area of the requested message, queries the Delivery Context Database and the Context Tracker if each client's context matches the delivery context of the message, and disseminates the message to the matched clients.

Fig.5 exemplifies interworking between the function components in the second alternative. As a step before the start of the sequence, the Geo-messaging server receives a message and stores the delivery context of the message in the Delivery Context Database. The Delivery Context Database generates new state machines by taking the received delivery context into account, and provisions the Context Tracker of a client with a state machine, if the client enters into an geographical area that a state machine designed specifically to the area needs to be used. The Geo-Messaging can be utilized as the delivery means of the state machine. When a car passes by an ITS spot the DSRC OBU communicates with the ITS spot and receives the ITS spot identity. The received ITS spot identity is forwarded to the Road segment identifier in the smartphone, through the DSRC OBU Connector which is omitted in Fig.5. The Road segment identifier looks up the highway road segment on which the car is currently traveling. Based on the given highway road segment information and the current mode of transport, the Context Tracker returns a Context ID and makes the Geo-messaging client subscribe for the Context ID. When a car comes into a destination area of a message, the Geo-messaging server looks up the Context ID of the message in the Delivery Context Database, and if it matches with the Context ID reported by the client, the Geo-messaging server sends the message to the client, which in turn is passed to the application in the smartphone.

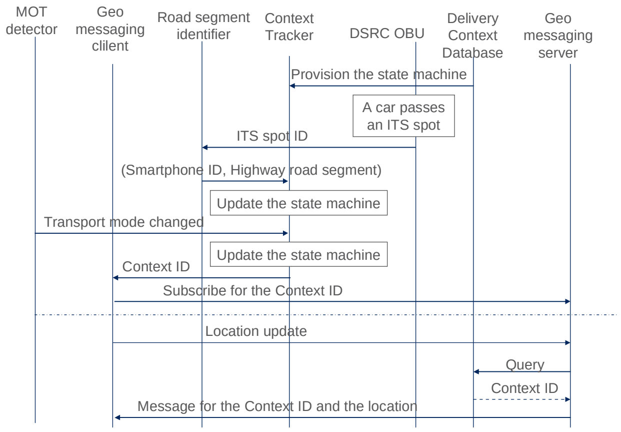


Fig.5 Sequence diagram of alternative 2

Note that the sequence below the long dotted lines in Fig.4 and Fig.5 are common to both alternatives. In Fig.4 the Geo-Messaging server distributes a message when the message is received. In Fig.5 a message which has been stored in the Geo-messaging server is delivered to a client when the client reports the update of the location to the Geo-messaging server. Combination of both sequences ensures a message is delivered to a client no matter if the client has already been in the destination area or if the client comes into the destination area after the Geo-messaging server receives the message.

3.3 Comparison between the alternatives

In our solution identification of a road segment and direction takes an important role of screening right group of information receivers. For example, the second use case in section 2 delivers coupons as incentives to the driver on highway to change their behavior to reduce the congestion, and it is inappropriate if the system allows a driver traveling on an ordinary road under the highway to receive such coupons by compromizing the road segment identification. An advantage of the first alternative is that a user can not compromise the Road segment identifier because it is deployed on the server side and relies on the ITS spot ID reported by the ITS spots server. In case of the second alternative a malicious user may compromise the Road segment identifier to report a road segment to the Context Tracker even if the car is actually travelling somewhere else. On the other hand, the first alternative has a disadvantage in terms of scalability because the Context Tracker maintains the state machines of individual clients. In the second alternative the Context Tracker resides in the client side and thus the solution is easier to scale.

The number of messages to be exchanged between the server side components and the smartphones over the air is different between the two architecture alternatives. To estimate the number of messages exchanged for updating user's context information and message transmission in each alternative, we consider the following model.

- T : Travel time of a car
- Δt_m: Time interval with which the MOT detector reports the current transport mode.
- P_t: Probability that a reported transport mode is different from the previous transport mode (i.e. Transport mode change probability).
- N : The number of times the state machine is updated during the travel time T.

In the first alternative, a message is sent from the client whenever the transport mode changes. During the travel time T the MOT detector reports the transport mode for $T/\Delta t_m$ times and the proportion Pt of them changes the transport mode. So, the number of messages N(alt.1) during the travel time T is modeled as in equation (1). On the highways even though the transport mode remains as the driving mode for most of the time, the MOT detector can report the walking mode by error when a car travels slowly due to congestion.

$$N(alt.1) = \frac{T}{\Delta t_m} P_t \qquad (1)$$

In the second alternative, the Delivery Context Database sends N messages for updating the state machine in the Context Tracker which resides in the client. In addition, a client sends a message to change the Geo-messaging service only when the state machine outputs a different Context ID from the one that the Geo-messaging client currently subscribes for. Below let us introduce additional parameters for the second alternative. Fig.6 gives a graphical explanation of these parameters.

- $\boldsymbol{t_i}$: The time when the Context Tracker was updated with a new state machine $\boldsymbol{s_i}$.
- $P_s(\boldsymbol{s_i})$: The probability that a transport mode change causes the state change in state machine $\boldsymbol{s_i}$ (which triggers to send a message indicated as "Subscribe for the Context ID" in Fig.5).

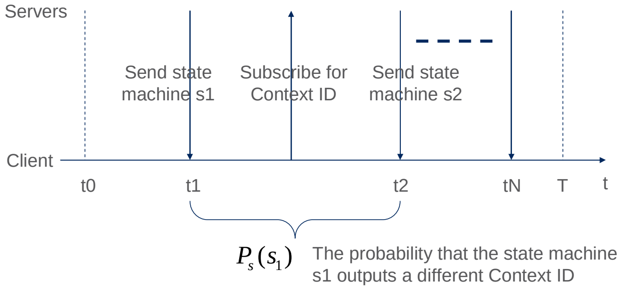


Fig.6 Explanation of parameters in alternative 2

During time period $(\mathbf{t_{i+1}} - \mathbf{t_i})$ the state machine $\mathbf{s_i}$ outputs a different Context ID than the previous one with probability $\mathbf{P_s(s_i)}$, which makes the Geo-messaging client to send a message to change the Context ID. The number of messages sent during this time period is given by.

$$\frac{(t_{i+1} - t_i)}{\Delta t_m} P_t P_s(s_i) \tag{2}$$

The Context Tracker is updated once at every $\mathbf{t_i}$. The number of messages exchanged between the server side and the client are expressed by equation (3).

$$N(alt.2) = \sum_{i=0}^{N-1} \left\{ \frac{(t_{i+1} - t_i)}{\Delta t_m} P_t P_s(s_i) + 1 \right\} \tag{3}$$

Here, the travel time T equals to the sum of $(t_{i+1} - t_i)$ for 0 <= i <= N-1. Thus, the difference of the number of messages between the two alternatives is expressed by equation (4).

$$\begin{aligned} &N(alt.1) - N(alt.2) \\ &= \sum_{i=0}^{N-1} \frac{(t_{i+1} - t_i)}{\Delta t_m} P_t - \sum_{i=0}^{N-1} \left\{ \frac{(t_{i+1} - t_i)}{\Delta t_m} P_t P_s(s_i) + 1 \right\} \\ &= \sum_{i=0}^{N-1} \left\{ \frac{(t_{i+1} - t_i)}{\Delta t_m} P_t \cdot (1 - P_s(s_i)) - 1 \right\} \end{aligned} \tag{4}$$

In equation (4), $1-P_s(s_i)$ is the probability that the state machine outputs the same Context ID when the transport mode changes. For example, if the walking mode is detected on the middle of highway where there is no parking areas around, the state machine can ignore the walking mode because it is unlikely that a person walks on a highway, which outputs the same Context ID and thus does not trigger sending a message to re-subscribe for the Geo-messaging server. On the other hand, the MOT detector in the first alternative blindly reports every single transport mode changes to the Context Tracker in the server side. The effect of removing errornous transport mode changes in the second alternative is included in the probability $1-P_s(s_i)$.

In this section we compared the two architecture alternatives in two aspects. One is the possibility of compromising the road segment identification by malicious users, and the other is the number of messages exchanged between the servers and the clients. The architecture alternative for a specific service should be selected primarily based on whether the service requires tolerance against malicious users compromising the road segment identification to report a road segment they are not currently traveling on. Services such as road charging and traffic flow controls are considered intolerant to the compromise, and for such a service the first alternative is preferred to the second because the first alternative provides better security features. From the signaling efficiency perspective, if the probability of erronous detection by the MOT detector is high and the number of messages depending on the transport mode which is a part of the delivery context is large, the second alternative is better than the first.

4. Prototype

We implemented major parts of the proposed solution as a prototype system. The second architecture alternative was selected because we did not have an access to the ITS spots server in our study. Fig.7 depicts the prototype system. The colored boxes are the functional components reusing existing software and the white boxes are the newly developed ones.

As for the Geo-messaging server and client we used Geo-Location-Messaging (GLM) API and the Android GLM client provided by Ericsson Labs respectively [2]. In the GLM system the world is split by grids into tiles with approximately 4km size and a client registers its location when the client moves across a grid. When the Geo-messaging server is requested to deliver a message, the server looks up the tiles which is covered by or crossing the message's destination area, and disseminates the message to the clients in the tiles. A Geo-messaging client checks if it resides in the message destination area, and if it is the case the message is delivered to the application. The Geo-messaging is an important component in the Cooperative ITS (C-ITS) area and it is currently being standardized in ETSI ITS [11][12].

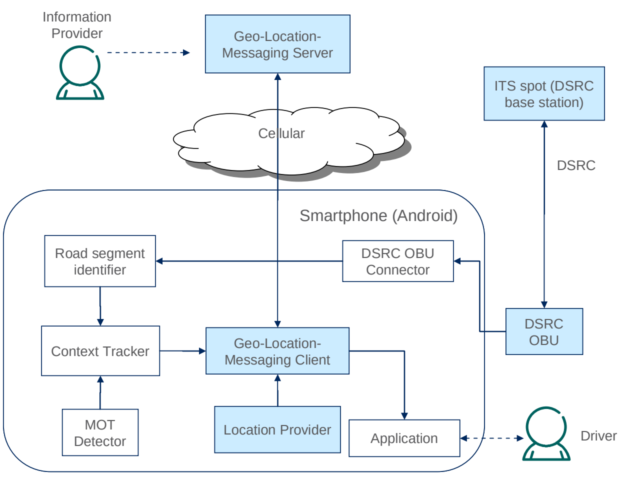


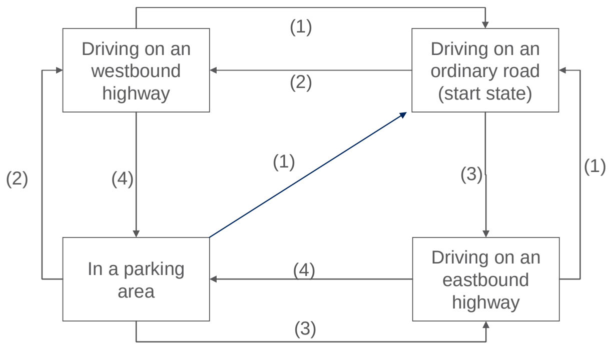
Fig. 7 Prototype of the 2nd architecture alternative.

The DSRC OBU that we used for the prototype has a serial interface to export received DSRC messages. Because smartphones usually do not have any serial interface, we put a PC as an intermediary between the smartphone and the DSRC OBU which converts the serial connection to the Bluetooth connection. The DSRC OBU connector function in the smartphone parses the DSRC messages and generates a detected event among the following: connected to the OBU, disconnected from the OBU, and passing an ITS spot.

The MOT detector processes acceleration sensor readings and GPS speeds to estimate the user's transport mode in one of the stationary, walking, and driving modes. The three classifications are sufficient for our prototype. The algorithm is based on the one proposed by Reddy et al. [5]. Firstly, the walking mode or not is detected by applying the Decision Tree for the acceleration sensor readings. If the user is considered not walking, then stationary or driving mode is distinguished by using the velocity obtained from the GPS.

The Context Tracker in the client side listens to the events from the DSRC OBU connector and the MOT detector. Depending upon the current state and the occurred event, it updates the internal state and outputs the Context ID corresponding to the new state. Although the GLM server and client do not have the concept of Context ID, they support multiple services where different contents can be delivered. So, delivery of different contents for each Context ID could be realized by mapping Context ID to the GLM service ID. Fig. 8 depicts the state machine in the Context Tracker. A number attached to an arrow means the condition which causes the state transition. When a state transition occurs, the state machine outputs the new state's name as the Context ID. When the Context Tracker is started, it enters the start state meaning that the car is traveling on an ordinary road. In this prototype the information receivers are limited to the users on highways, so the GLM client does not subscribe for any services in the "Driving on an ordinary road" state.

Prototyping and evaluation of the Delivery Context Database is a future study item. In the current prototype the delivery context for a message is mapped to a Context ID manually, and the state machine for selecting a right Context ID is preset in the Android application.



(1) DSRC OBU disconnected.
(2) Passing an ITS spot on an westbound highway.
(3) Passing an ITS spot on an eastbound highway.
(4) Transport mode changed to "walking".

Fig. 8 State machine.

5. Verification by experiments

We verified the designed functionalities of the solution through several test drives using the prototype system on the highways in Chiba prefecture as depicted in Fig. 9. The test drive course consists of two highways with a parking area for each direction. Note that there are 10 ITS spots within the experimental field. Each ITS spot is depicted as a marker and its color indicates direction of highway (black for eastbound, white for westbound). Note also that we set 7 message destination areas in the experimental field. Each destination area is depicted as a rectangle and pattern of rectangle indicates direction of highway (stripe for eastbound, lattice for westbound, gray for both). The small pictures indicated in the map are the advertisements delivered in each destination area. The browser screen at the left bottom corner of the figure indicates that a separate advertisement is delivered to a driver in the parking area indicated by the gray message destination area, and presented by a full browser when the driver gets off the car and starts walking. The advertisement messages to be disseminated and their destination areas were pre-registered with the server for simplifying the drive tests.

Fig. 9 Information received on the test drive course.

We confirmed that the system could distinguish the highway road, its directions and segments by receiving the ITS spot identity by the DSRC OBU, subscribe for the Geo-messaging service for the specific highway directions and segments and the transport mode, and then receive messages delivered via the Geo-messaging. Messages destined to a highway road were not received by the clients on an ordinary road or on the opposite highway lane even though those roads were covered by the message destination area. While a driver was driving a car after entering a parking area, a message destined to the parking area was not presented to the driver. When the driver parked and left the car with his/her smartphone, the change of the driver's transport mode was successfully detected and the message was displayed on it so that the driver could see the information about the parking area with richer presentation.

6. Related works

One could argue that the highway road segment where a car is currently traveling can be identified by using a map matching technology. For example Newson et al. proposed a map matching algorithm based on the Hidden Markov Model (HMM) and made the algorithm robust to location data that is both geometrically noisy and temporally sparse [9]. Although the algorithm may perform well with the GPS sensors in smartphones, a user can easily fake the GPS location by using smartphone applications available on the market and a user can easily get one for the sake of protecting his or her privacy and for other purposes. The first alternative of our proposed architecture identifies the road segment at the server side by using the information a user passes an ITS spot and thus an end user cannot fake it. Some applications like a coupon system may be intolerant to faked road segments, and then use of the ITS spots as proposed in our paper may complement the map matching based road segment identification.

Grim proposed an embedded gateway module which facilitates V2X communication, while the V2X features are hosted on a passenger's smartphone and the gateway is only used for enabling DSRC communication [4]. This approach enables a lightweight deployment that reduces the impact to vehicle electrical architectures. Bluetooth is used for the communication between the embedded gateway module and the smartphone. They did not touch upon the use of the ITS spot as a way to identify which highway road segment a car is traveling which is a difference from our proposal.

Efatmaneshnik et al. proposed to use DSRC for cooperative positioning to complement the GNSS positioning which is sometimes inaccurate [3]. Cooperative positioning is useful to identify a car location especially when the car is close to tall building and under a highway which degrades the GPS accuracy. However, their solution requires wide deployment of DSRC OBU with V2V communication capability. Our approach leverages reuse of already deployed the ITS spot infrastructure for ensuring that a car is traveling on the highway where an ITS spot is installed.

For delivering a message to a certain geographical area, efficient localization of clients is crucial. In the prototype system we used the Geo-messaging system with the grid-based localization. Efficiency of the grid-based localization over the time-based localization and distance-based localization for Geo-messaging was studied by Jodlauk et al [6]. In addition, whether the cellular network is usable for a time critical application such as delivery of hazard warning messages has already been studied by Jodlauk et al [7] and by the CoCarX project [1]. Thus, we did not evaluate the performance of the Geo-messaging function in this paper.

7. Conclusions

In this paper we proposed a context-aware information delivery system to highway users, in which the information delivered over the cellular networks and the DSRC infrastructure are effectively combined. The system gives the information senders the flexibility to specify the highway roads and its direction, the geographical areas, and also context in terms of whether the driver is driving or walking in a parking area, as the destination of the information. We prototyped a part of the proposed solution architecture and verified the functionalities by the prototype through the test drives. We conclude that the fundamental part of the solution supports realizing the use cases including the one discussed in this paper, which come from discussions with road operators and other business entities in this field.

A future work item is enhancement of the mode of transport detector to distinguish more transport modes than the walking and driving modes. Such an enhancement will give further flexibility for the information senders to specify the receivers. Another future work item is feasibility study of delivering the information over the already deployed DSRC infrastructure, and providing the unified interface to the information senders so that they are not bothered by selection of appropriate delivery means.

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