A QoS Management Technique of Urgent Information Provision in ITS Services Using DSRC for Autonomous Base Stations

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SUMMARY A QoS management technique based on an autonomous decentralized mobility system, which is an autonomous decentralized system enhanced to provide mobile stations with information about urgent roadway situations, is proposed in this paper. This technique enables urgent messages to be flexibly and quickly transmitted to mobile stations by multiple decentralized base stations using dedicated short range communication. It also supports the easy addition of additional base stations. Each station autonomously creates information-delivery communities based on the urgency of the messages it receives through the roadside network and the distances between the senders and receivers. Each station dynamically determines the urgency of messages according to the message content and the speed of the mobile stations. Evaluation of this technique applied to the Smart Gateway system, which provides driving-assistance services to mobile stations through dedicated short-range communication, demonstrated its effectiveness and that it is suitable for actual systems.

key words: autonomous decentralized system, community, ITS, mobile communication, QoS, DSRC

1. Introduction

Intelligent transport systems improving travel efficiency and driver safety, such as vehicle information and communication systems (VICS) and the advanced cruise-assist highway system (AHS) [12] using short-range communication, have already been put into practical use and field-tested [1]. The services are expected to be improved by using decentralized multiple base stations (BSs) system with dedicated short-range communication (DSRC), called a smart gateway (SG) system [2]. In a SG system these services must be provided flexibly according to the running environment of a MS. Urgent messages such as those containing accident information, for example, must be transmitted within milliseconds to the MSs near the accident site so that it can be used to control the movement of the vehicles containing those MSs but can be transmitted with some delay to MSs farther away because the drivers of the vehicles containing those MSs do not expect vehicle control but simply want to avoid the traffic jam caused by the accident. It should also be easy to add new BSs without affecting the ones already in the system.

This flexibility and expandability are expected to be provided by the Autonomous Community Information System (ACIS) [14], [15], the development of which was inspired by the spirits of cooperation in the social communities and by the Autonomous Decentralized System (ADS) concept [6]–[8]. The ACIS customizes the service for the specific end-users (community members) having interests in that service, in somewhere/anywhere, at specified time. Although the ACIS can therefore offer flexible and scalable information provision, its use in road traffic will be limited because in the ACIS at least three community members must be defined in advance. In road traffic it is difficult to create the community using BSs in advance because when and where situations requiring the transmission of urgent information cannot be predicted. On the other hand, urgent messages can be sent immediately to the appropriate MSs by using any of several techniques proposed for transmitting urgent messages to MSs in order of priority. A DSRC BS simply sets the priority levels of the messages and transmits them on the basis of their priority levels [3]–[5]. Those techniques, however, do not use several BSs to transmit a single urgent message. Additionally, several techniques based on the ADS architecture have been proposed for supporting high expandability [9], [10]. Each BS autonomously determines which messages to send to which MSs and sends them accordingly. However, these techniques cannot transmit messages in order of priority because each BS simply transmits them in the order that they were received from the other BSs. Therefore, it is also difficult to meet the requirement for flexible information provision when using the above techniques.

This paper therefore proposes an autonomous decentralized mobility system (ADMS) that enables an information-delivery community consisting of some BSs to be created autonomously according to the urgency of the information, the distance between the accident site and the MSs, and the speed of the MSs. It also proposes a quality of service (QoS) management technique in which each autonomous BS (ABS) in information-delivery community autonomously judges the content of information according to the urgency for each MS and provides it for the MS. Application of this technique to SG system, which provides a variety of information services for running vehicles by using multiple decentralized DSRC BSs set along the road, demonstrated its effectiveness.

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2. Smart Gateway System

2.1 System Configuration

An example configuration of an SG system is shown in Fig. 1. It uses DSRC to provide driving-assistance information (about vehicle accidents, obstacles in the road, etc.) and traffic information (a map of the surrounding area, the presence of a traffic jam, etc.) to MSs traveling at speeds up to 180 km/h on the basis of ARIB STD-T75 [13]. An example on which SG system works is the highway. Several BSs are set along the road at intervals of several hundreds meters, and an MS can receive the information when it is within the communication area of a BS (i.e., within a 30 m radius). SG system is consisted of several domains and a domain is consisted of several BSs, a few Local Servers (LSs) which provide the traffic information for MSs and are set in Service Areas (SAs), and the roadside network connecting between BSs and LSs. For example, the range of a domain is defined as the distance between SAs. The scope of this paper is the system of a domain. Driving-assistance information is detected by several sensors set along the road and is transmitted to MSs as an event-driven urgent message. When urgent driving-assistance information is detected by these sensors, it is transmitted to BSs through the roadside network every few hundred milliseconds until its urgent status is cancelled. A local server also transmits the traffic information repeatedly but at intervals of a few seconds or a few minutes. Urgent messages are so small that handover between BSs is not needed for them, but the larger messages providing traffic information will be provided using several BSs. In this study we consider each BS to have several sensors for detecting urgent information and consider urgent messages to be sent by the sensing application of a BS. The traffic information provision using handover is not discussed in this paper.

Each MS contains on-board equipment (OBE) for DSRC and transmits the information received from a BS to a vehicular terminal (VT), such as a car navigation device, through an in-vehicle network. When the VT receives an urgent message, it judges on the basis of the message's content whether the information should be provided to a driver or transmitted to an electronic control unit (ECU) and either provides it to the driver or transmits it to the ECU.

Fig. 1 Smart gateway system.

2.2 System Requirements

(1) Flexibility

Urgent information (such as information about a vehicle accident on the road) must be provided flexibly according to the relation between the urgency of the information and the distance between the accident site and the MS. To a MS near the site of an accident it should be provided as a control request, but to a MS far from the accident site it should be provided as information accompanied by alternative-path information the driver can use to avoid traffic jams.

(2) Performance

When the urgent information is provided as the control request, it must be provided to an MS immediately. And so, the urgent information detected by the time when the MS enters in the next cell must be provided to the MS at the next BS. In this case, the most critical case is that the detection of urgent information and the connection establishment between a BS and an MS happen at the same time. The communication area of a DSRC is very narrow (30 m), so a BS can communicate with an MS for only a very short period. For example, if the vehicle is traveling 180 km/h, the communication time is 0.6 s. Additionally, since the detection of an urgent situation takes about 500 ms to process [11], the message must be transmitted within 100 ms in the above condition.

(3) Expandability

Although multiple BSs are needed to provide coverage for a roadway, the initial budget may not be sufficient for installing all of them at the same time. It is likely that additional BSs will be added step-by-step as the service area is expanded. Therefore, step-by-step, easy addition of BSs is required.

2.3 Problem

In Autonomous Community Information System (ACIS) architecture it is possible to provide information flexibly because the community is autonomously created by several nodes having the same objectives, common interests and demand at specified time and somewhere/anywhere and each node autonomously judges whether to join or leave the community network according to its user's preferences [14], [15]. A community of at least three nodes must be defined in advance, however, because in the ACIS the community members are linked on the basis of Hamilton cycles. Accordingly, it is difficult to apply ACIS architecture to a SG system because the times and locations at which situations producing urgent information will occur are not known in advance. Additionally, several techniques have been proposed for enabling high-speed transmission of urgent messages [3]–[5] on the basis of an assigned priority level. They do not differentiate between the priorities of urgent mes-

Fig. 2 Autonomous decentralized system architecture.

sages and they assume that the information is provided by only one BS. Therefore, if these techniques are applied to a SG system consisting of several BSs, all the BSs will transmit the urgent message with top priority. This will not satisfy the requirement for flexible information provision. While other techniques based on the ADS architecture [6]–[8] support step-by-step, easy addition of BSs, they simply send the messages in the order that they are received [9], [10]. Each BS autonomously determines which messages should be sent to which MSs from among the messages transmitted through the roadside network from other BSs by using broadcast communication. The first message in the queue is sent immediately to those MSs within range of the BS regardless of whether it is the most urgent one. The reason for this is that the conventional ADS architecture was not designed to support MSs.

The ADS architecture (Fig. 2) comprises autonomous subsystem (ATOM) and data field (DF), which are used to exchange messages between the ATOMs. Each ATOM has a self-management program (autonomous control processor or ACP) and an application program (AP) that runs the application processes. Each message sent to a DF has an attached service identifier (SID) identifying the service content of the message. The ACP autonomously selects messages from the DF on the basis of the SID, processes the messages using the AP, and broadcasts them to the DF. Each ATOM is at an equal level and selectively receives those messages from the DF for which the SID corresponding to an AP was registered in the ACP beforehand. However, this architecture does not support the movement of APs between ATOMs, so a message from the ACP to an AP is the same for all ATOMs if all ATOMs have the same AP. When the ADS architecture is used for service provision, a BS sends messages received through the roadside network from other BSs to the MSs in the order in which they were received because, in the SG system, the ATOM, DF, ACP, and AP correspond to the BS, the roadside network, the BS's program, and the MS's program. As a result, urgent messages are not transmitted to the MSs flexibly.

3. QoS Management Technique for Autonomous Base Stations

3.1 Autonomous Decentralized Mobility System (ADMS)

An autonomous decentralized mobility system (ADMS)

Fig. 3 Autonomous decentralized mobility system architecture.

based on ADS architecture is proposed in order to solve the problems described in Sect. 2.3. Each subsystem in an ADMS autonomously creates the information-delivery community on the basis of the urgency of the information, the distance between the MS's position and the urgency site, and the MS's speed.

3.1.1 Concept

In an ADMS (Fig. 3), each ATOM autonomously creates the information-delivery community in order to transmit the message to an MS. The creation of this community is based on the urgency of the information, the distance between ATOMs, and the speed of the MS. The urgency is defined, according to both the kind of the information and the safe stopping distance. The message flow in the DF is shared by ATOMs in the community. There are two logical subcommunities in the information-delivery community, one of which is the information community and the other of which is the control community, and each subcommunity is created dynamically. In the information community, the urgent information does not need to be transmitted to an MS immediately because it is dealt with as traffic information. In the control community, on the other hand, the urgent information must be transmitted immediately because it is a control request for a MS. The MS deals with the information received from each ATOM in the information community as traffic information and uses it for route guidance to avoid the traffic jam. On the other hand, the MS deals with the information from each ATOM in the control community as a control request and uses it for warning the driver and/or as a control request to the ECU for slowing down.

3.1.2 System Components

An ADMS introduces a QoS management (QM) mechanism into the ADS. A QM mechanism has a node identifier (NID) and a node location (NL) as the ATOM's profile information. The NL is expressed as latitude and longitude. A QM mechanism has also the profile information of other ATOMs in the ADMS. When a new ATOM is connected to the DF, it transmits its self-profile information to other ATOMs in the ADMS. Furthermore, a QM mechanism holds the urgency defined below for each information kind. The definition of

An autonomous community creation is shown in Fig. 4. The ATOM that detected the urgent information attaches a SID, CID, and NL to the detected data and sends the urgent message to the DF with the highest priority. Each ATOM connected with the DF judges, according to the SID, whether

As shown in Fig. 5, each ATOM in the community sends the MAP information to the others in the community when an ATOM disconnects from a MAP. The disconnecting ATOM sends the subcommunity creation request (which is composed of the SID, CID, NL, and disconnected MAP information) to the others in the community if its information is not registered in the community table. The ACP of each ATOM in the community receives the request if the SID corresponding to its own SID. If so, the ACP passes it to the QM mechanism. If CID in it is the same as CID registered in the community table of itself, the QM mechanism receives it. Then, the QM mechanism calculates U_{map} from velocity V attached to the request and D_i registered in the community table and judges the subcommunity. Additionally, it adds the MAP information and the community's property to the

Fig. 8 Transmission of MS information in SG system.

it to the QM mechanism if it is the urgent message. The QM mechanism autonomously judges whether to join the community, and this judgment is based on the urgency U and the distance D_i calculated using the NL_i of itself and the sender NL determined from NID attached to the message. If the ABS joins the community, it registers to the community table the SID, CID, NID, and data attached to the message. At the same time, the time-out timer in the community table is set. Each ABS in the community dynamically determines the subcommunity it should belong to according to the following condition. If $D_i \leq U_{map}$ or $(D_i > U_{map}) \wedge (D_{i+1} \leq U_{map})$, the ABS judges the control community. The other ABSs in the community judges the information community. Additionally, the ABS in the control community confirms the position of itself within the control community, determines the kind of message such as a warning, a control request, and so on., and sends it to an MS.

4.3 Transmission of MS Information in SG System

As shown in Fig. 8, the ABS disconnected with a MS sends the subcommunity creation request attached to the SID, CID, NID, and MID of the MS to the roadside network if the MID is not registered in the community table. The ACP of each ABS in the community judges, from the SID, whether to receive the request and gives notice it to QM mechanism. The QM mechanism noticing the request from the ACP autonomously judges whether to receive the request, basing this judgment on the CID registered in the community table. If the QM mechanism receives the request, it registers the MID attached to the request in the community table and dynamically determines the community's property as well as 4.2. Additionally, it adds the MID and the community's property to the community table. When the ABS connects with the MS through DSRC, it sends the message to the MS according to the community's property. If there are several communities for a MS, the shorter D_i has, the higher priority.

4.4 Disappearance of Community in SG System

Each ABS disconnecting from a MS deletes the MID of

Fig. 9 Disappearance of community in SG system.

the MS from the community table and breaks away from the subcommunity. Additionally, as shown in Fig. 9, if the time-out timer set in the community table has expired, the community table is deleted and all subcommunities in the community table are deleted. On the other hand, if the urgent situation is canceled, the time-out timer is not renewed and the community disappears.

5. Evaluation

5.1 Experimental System

5.1.1 Experiment Composition

We evaluated proposed technique by using an experimental system composed of several ABSs and a LS in Oyama city, Tochigi prefecture. The experimental system configuration is shown in Fig. 10 and its specifications are listed in Table 1. In this system, the number of ABSs is seven and the distance between ABSs is 50 m. The IEEE802.3 was used for the roadside network, which had a communication speed of 100 Mb/s. The ABS consisted of a system board implementing the proposed technique, a 200-MHz CPU (SH7750), and a DSRC board based on the ARIB STD-T75 standard [13]. The urgent message was sent from the test program (TP) installed in the ABS. A LS was also connected with the roadside network and sent the traffic information to a MS through several ABSs. The in-vehicle network comprised an information terminal for receiving the information transmissions and onboard equipment for DSRC connected through IEEE802.3. The message from an ABS to a MS was transmitted using one communication channel of DSRC, the communication speed of which was 0.2 Mb/s. The maximum vehicle speed in this experiment was 40 km/h, and the V_c for MAP information was also 40 km/h.

5.1.2 Experimental Method

(1) Confirmation of flexible information provision

In this experiment, we made the TP on the ABS#7 send the urgent message every 100 ms and a LS send a map data to the vehicle. We evaluated whether or not the information terminal could receive three different messages when the vehicle passed through several communication areas of ABSs.

Fig. 10 Configuration of experimental system.

Table 1 Specifications of experimental system.

The number of ABSs	7
The distance between ABSs	50 m
The number of LS	1
LS	Desktop Computer
CPU of ABS's system board	SH7750 (200 MHz)
DSRC	ARIB STD-T75
The communication technique between ABS-MS	Peer-to-peer (Max:0.2 Mb/s)
Roadside Network	IEEE802.3 (100 Mb/s)
Vehicle's speed	Max:40 km/h
The number of vehicle	1
In-Vehicle Network	IEEE802.3 (100 Mb/s)
Information terminal	laptop

The messages that should have been sent from the ABS in the control community were “Warning,” and “Stop.” The “Attention” message was used by the ABS in the information community. An image corresponding to the received message was displayed on the information terminal in the vehicle. $D_s = 150$ and the parameter values in expression (1), used by each ABS to determine the subcommunity it should belong to, were $\alpha = 1$, $\mu = 0.7$ (dry road), $T = 0.8$ (average time), and $V = 40$.

(2) Performance measurement of sub-community creation request

For high-speed transmission of the urgent message in the control community, the subcommunity creation request must be transmitted from the sender ABS to the receiver until the vehicle connects with the neighbor ABS. We therefore measured the transmission time of the subcommunity creation request, which is the time from when a QM mechanism recognizes the disconnection from a MS until the MS's information is registered in the community table of a QM mechanism in another ABS. The request size is 256 Bytes which includes the 64-Byte protocol header. The target performance was 10 ms, which is the time required for connection between a BS and a MS through DSRC [16].

(3) Performance measurement of urgent message transmission

Each ABS in the control community must transmit an urgent message to a MS immediately regardless of the

Fig. 11 The evaluation result of flexibility.

amount of data transmitted from LS. We therefore measured, in an environment in which the roadside network load (produced by a packet generator) was 0.2 Mb/s, the time from when a TP sent an urgent message until the information terminal in the vehicle received it. The urgent message size was 256 Bytes which includes the 64-Byte protocol header. The target performance, 100 ms, was based on the shortest communication time between an ABS and a MS and the detection time of the urgent information. The shortest communication time was 600 ms because the communication area was 30 m, the maximum vehicle speed (based on ARIB STD-75 [13]) was 180 km/h, and the detection time was the 500 ms required for AHS services [11].

5.2 Evaluation Result

(1) The evaluation result of flexibility

The results of evaluating the flexible information provision are shown in Fig. 11. In this experiment we confirmed that the information terminal displayed the map data when the vehicle passed through the communications areas of ABS#1 through ABS#4 and displayed “Attention,” “Warning,” and “Stop” when the vehicle passed through the communication areas of ABS#5, ABS#6, and ABS#7. This result indicates that ABS#5, ABS#6, and ABS#7 are joined in the community because the distance between ABS#5 and ABS#7 is 150 m. Additionally, ABS#6 and ABS#7 are belonged to the control community because $U_{map} = 46$ m and ABS#5 is belonged to the information community. Each ABS in the community autonomously judges the message kind according to its property. On the other hand, a map data was displayed on the information terminal when the vehicle passes through from ABS#1 to ABS#4. This result indicates that each ABS didn't join the community because $D_i > D_s$ (i : from 1 to 4). And so, we confirmed the flexible information provision properly functioning using the proposed technique.

(2) The performance result of sub-community creation request

In this evaluation, we measured three times and got an average of 2.63 ms, which is within the 10-ms target performance. Although in this evaluation there was no load on the roadside network, it is known that the result would not be affected by the roadside network loads if the roadside network

Fig. 12 The performance result of the urgent message transmission.

load is lower than 10 Mb/s [16].

(3) The performance result of the urgent message transmission

The evaluation results are plotted in Fig. 12. The horizontal axis represents the running measurement time, and the vertical axis represents the time it took to transmit urgent messages. When there was no load, the urgent message transmission time with the proposed technique was virtually the same as with the FIFO technique (about 56.7 ms on average, which meets the required 100 ms). Even when the load was maximum, the average time with the proposed technique was still only 70.9 ms, compared to 102.6 ms with the FIFO technique. The time was longer with the FIFO technique because, when the ABS received an urgent message from the roadside network, it sent it to the MSs in order which they were received by the ABS, so, when the communication load was higher, the transmission time was longer. In contrast, with our proposed technique, the QM mechanism can send the most urgent message to the MSs even when the communication load is high because the QM mechanism dynamically determines the message urgency. The difference in transmission times with our proposed technique for the load and no-load conditions is accounted for by the times for ACP and QM mechanism because, as the number of messages received from the roadside network increases, the SID search process and urgency comparison process take longer. Nevertheless, our proposed technique can meet the 100-ms requirement even if there is a load. The proposed technique is thus effective for high-speed transmission of urgent messages.

(4) Speculations of the roadside network for expandability

Because the communication between ABSs in an ADMS uses a content-code communication technique that does not assign the destination address to the message but instead assigns a SID, CID, and NL, several ABSs can be added easily even if the system is on-line. On the other hand, since this technique uses the broadcast communication, it is necessary to consider the roadside network load. The roadside network load is greatest when conditions 1 and 2 described below both hold.

Condition 1: All ABSs connected with the roadside network send urgent messages to the roadside network.

Condition 2: All ABSs connected with the roadside network send the subcommunity creation requests for several MSs disconnected from each ABS.

If the 256-Byte urgent message is sent to the roadside network every 100 ms, the sending throughput of each ABS is 20 kb/s. And if each ABS disconnects from two MSs at one-second intervals, the sending throughput of each ABS is 4 kb/s. Accordingly, the total throughput of an ABS is 24 kb/s under the above conditions. Because the message transmission of the roadside network is not delayed if the load is not greater than 10 Mb/s [16], the maximum number of ABSs connecting with the roadside network is 426. Moreover, if the distance between ABSs is 100 m, the range of one domain in a SG system is 42.6 km. This means that the roadside network load by the broadcast communication does not cause any grave delay because the domain size is assumed to be much smaller than 42.6 km.

6. Conclusion

A QoS management technique, as embodied in an autonomous decentralized mobility system based on the enhanced autonomous decentralized system architecture, enables multiple decentralized base stations using dedicated short range communication to flexibly and quickly transmit urgent messages with information about vehicle accidents, roadway obstacles, etc. to mobile stations. It also supports the easy addition of BSs as the system is expanded. Each BS autonomously creates the information-delivery community on the basis of the urgency of each message it receives through the roadside network and the distance between the sender and receiver. Each BS can thus send messages to the MSs flexibly and quickly because the BS in the community dynamically judges the message content according to the property of the community which is determined from the urgency of the message and the speed of a MS and sends it to a MS. Additionally, since the message flow in the roadside network is not assigned the destination address, a system using this technique can be expanded easily. Evaluation of this technique applied to the Smart Gateway system demonstrated its effectiveness and that it is suitable for actual systems.

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