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***Abstract*—Vehicle-to-vehicle (V2V) messaging is an indispensable tool for real-time dynamic information sharing in cooperative Intelligent Transportation Systems (ITSs). Although V2V standards are specified in the European Union, United States, and Japan, all such standards suffer from a set of common drawbacks. In this paper, we first analyze these issues and derive a problem statement. We then propose a roadside-assisted V2V messaging scheme in which roadside units construct a database of dynamic information obtained from sensors and transmit data to nearby and remote vehicles. We also design a common solution to the problem of differing regional standards by making the system independent of any specific set of standards. Finally, we analyze the potential requirements for designing a specification of roadside-assisted V2V messaging. The proposed system is designed to be technically compatible with 5G mobile edge computing.**

Keywords–Cooperative ITS; Vehicle-to-Vehicle; Standard; VANET; Internet

I. Introduction

Road transport is an essential infrastructure for supporting human activity; at the same time, it introduces many problems, including traffic accidents and congestion, air pollution, and increased energy consumption. Solving the problems of road transport is therefore a key to making road travel safer, more efficient, and more pleasant. Autonomous vehicles are currently attracting the attention of researchers and engineers; however, stand-alone autonomous vehicles simply replace human perception, decision-making, and maneuvering with computer control. Taking the concept one step further, Intelligent Transportation Systems (ITSs) can, for example, improve perception where there are blind spots in vehicle sensors by connecting vehicles to roadside units.

Road networks are interconnected among countries and, in the many cases where there are insignificant barriers, vehicles can easily cross country borders. To enable interoperability among countries, cooperative ITS need to be developed based on universal architecture, protocols, and technologies. To standardize cooperative ITS, the International Organization for Standardization (ISO) Technical Committee 204 Working Group 16 (TC204 WG16) (also known as Communications Architecture for Land Mobile (CALM)), in coordination with the European Telecommunications Standards Institute (ETSI) TC ITS, is developing a standard architecture for cooperative ITS called the ITS Station reference architecture [4], [3]. In the US, the Institute of Electrical and Electronics Engineers (IEEE) is standardizing a Wireless Access in Vehicular Environments (WAVE) architecture in the IEEE 1609 family of standards [5] as well as an IEEE802.11 variant for vehicular communication, IEEE802.11p [2].

Vehicle-to-vehicle (V2V) messaging is indispensable for implementing cooperative ITS involving real-time information sharing among vehicles of, for example, vehicle position data. As VRV message standards, the Cooperative Awareness Message (CAM) [8], Basic Safety Message (BSM) [1], and Advanced Safety Vehicle (ASV) have been specified in the EU, US, and Japan, respectively. Messages are transmitted by single-hop broadcasting via $5.8 \sim 5.9Ghz$ ITS wireless media (i.e. IEEE802.11p [2]) under the EU and US standards and by 760 Mhz ITS wireless media in Japan.

In theory, connected autonomous vehicles can be made aware via wireless single-hop V2V messaging of other, out-of-sight vehicles. However, the three schema described above have four potential problem areas: 1) mixed environments in which V2V message receivers cannot receive messages from vehicle without V2V transmitters; 2) V2V messages may be lost because of interference and obstacles filtering wireless communication; 3) communication ranges are limited to within the wireless range; and 4) V2V message exchange systems are vulnerable to malfunctions in sender vehicles and to malicious messaging.

In this paper, we first present an analysis of a problem statement on the above issues. To develop a potential solution addressing all the problems, we investigate a roadside-assisted V2V messaging scheme embodying a real-time cyber-physical system (CPS) comprising sensing technology and a V2V and Vehicle-to-Infrastructure (V2I) network. To take advantages of these technologies, we design a system that employs ITS dedicated media, cellular media, and IPv6. As V2V messaging systems under the EU, US, and Japanese share the four problems above, we investigate a common solution for all standards and propose adapting a layer of localization to the standards in each country.

The rest of the paper is organized as follows. Section II describes the problem statement on V2V message exchange. Section III presents details of our potential solution, called roadside-assisted V2V messaging. Section IV analyzes the requirements for the potential solution. Section V introduces related works. Finally, Section VI concludes the paper by summarizing the main discussion and addressing future work.

II. Problem Statement

In this section, we first describe a general scenario using the V2V messaging. Then, we analyse four potential issues arisen in the scenario.

A. Scenarios

In the ITS station reference architecture, neighboring vehicle information obtained by V2V messaging is stored in the Local Dynamic Map (LDM) [6][7] specified in the facilities layer, which provides a set of common functionalities shared by several applications for various tasks. The LDM supports various ITS applications by maintaining information on objects influencing or comprising the traffic, including highly dynamic data such as vehicle, roadside, and traffic conditions and the presence of accidents.

The LDM data, as updated by the V2V messaging, enables a connected autonomous vehicle to be aware of other vehicles out of the line of sight. Figure 1 illustrates a case in which the LDM provides accurate information to vehicles near an intersection. The lower layer of Figure 1 shows the physical space in which the road, vehicles, and a pedestrian are located, while the upper layer represents the parallel cyber space in which networked computers maintaining data that can be modified, exchanged, and shared. In the ITS station architecture, digital data received as CAMs from neighboring vehicles are stored in the LDM. In the following, we describe the protocol used the EU; however, the scenario described below applies in the US and Japan as well.

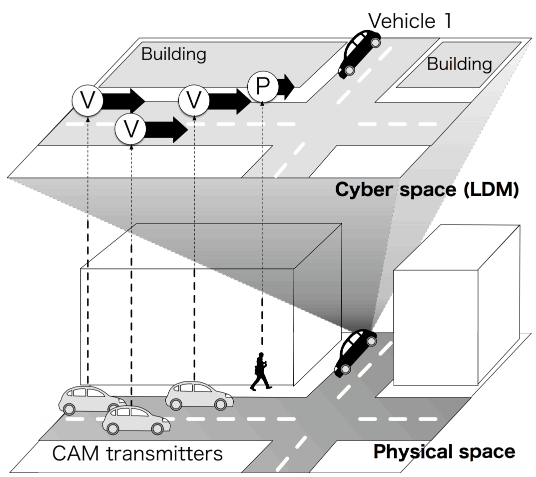

Figure 1. LDM and V2V messaging

In the case shown in Figure 1, vehicle 1 is made aware via a driver assistance alert of other vehicles behind the building. If the LDM provides accurate information that the other vehicles are not on a collision course, vehicle 1 does not need to stop before the intersection.

B. Issues

The above scenario assumes that all cyber-physical systems are working correctly, that V2V messages from all of the vehicles and the pedestrian are successfully delivered to vehicle 1, and that the LDM of the vehicle is kept up-to-date with respect to the surrounding environment.

In real situations, however, physical space information is often not projected correctly into cyber space. In the section, we describe the issues of cyber physical projection using V2V messaging.

1) **Mixed Environment:** To detect all vehicles using V2V messaging, all vehicles must be equipped with at least sender-side V2V device functionality. In this regard, the penetration of V2V devices is the key factor to enabling cooperative ITS. The US National Highway Traffic Safety Administration (NHTSA) had studied the possibility of implementing regulation to require V2V devices in new light vehicles [29]. However, regardless of the level of such deployment old vehicles will likely lack V2V devices, and thus we should consider mixed environments in which V2V-enabled vehicles operate among legacy vehicles.

Beyond legacy vehicles, it is important for cooperative ITS to accommodate pedestrians and bicycles, which are also generally not equipped with V2V sender devices. The current assumption of V2V messaging excludes such non-V2V aware nodes and therefore their presence is not projected into cyber space. Again, this strongly suggests that V2V messaging requires adaptation to mixed environments in which V2V-aware vehicles and non-aware nodes (legacy vehicles, pedestrians, and cyclists) coexist.

2) **Interference and Obstacle:** V2V messages are broadcast over ITS-dedicated media (ITS-5G or 760Mhz) within a single-hop distance. Messages may be lost in delivery if there are obstacles between the nodes that screen wireless radio propagation. On the road, such obstacles would include buildings, bridges, tunnels, hills, and heavy vehicles. In the above case that the V2V message does not reach the receiver, the physical information is not reflected accurately to the cyber space. The V2V receiver (Vehicle 1 in Figure 1) is not aware of the other vehicles presence or it is only aware of the old information. V2V messaging needs the solution to ensure message delivery.

3) **Limited wireless range:** V2V messages cannot be delivered beyond the range of wireless radio propagation from the sender vehicle. This range is often described as being from 500 m to 1 km when using ITS-5G in an ideal environment with a clear line of sight; however, the distance often becomes shorter in non-line-of-sight scenarios.

4) **Malfunctioning and malicious message:** In V2V systems, physical information is projected into cyber space based on data obtained from received V2V messages. In such cases, the receiver must be able to trust the sent information. To ensure trust, NHTSA's current research is based on the assumption that V2V systems will use Public Key Infrastructure (PKI) to authenticate messages [29]. However, such V2V systems would still be vulnerable to malfunctions of sender vehicles in which senders broadcast incorrect information (e.g., position, time, or speed). Such situations can be caused by GPS signal loss or metering device hardware problems. Alternatively, senders may broadcast V2V messages with incorrect information generated by software bugs or even false information generated by malicious software.

In the cases above, a receiver will generally not have the capability of validating the information in the V2V messages and incorrect physical data will be projected into cyber space. This underscores the importance of identifying and excluding incorrect or falsified physical information in the V2V message exchange process.

III. On the Design of Roadside-assisted V2V Messaging

To solve the issues of 1) mixed environments and 2) interference and obstacles described in Section II, we previously proposed a roadside assisted V2V messaging scheme called Proxy CAM. The system is compliant with EU V2V message standards (CAM) and can be adapted to the other standards (US and Japan) by adopting their V2V message formats (BSM and ASV, respectively). With some extension, the scheme represents a potential solution to all of the issues raised in Section II.

In this section, we briefly describe our previous work (Proxy CAM [20]) and then propose some extensions to Proxy CAM for a complete solution to all four issues raised in the preceding section.

A. *Proxy Cooperative Awareness Message*

An overview of Proxy CAM [20] is shown in Fig. 2. In the system, roadside sensors detect vehicles and obtain relevant information for each vehicle including position, velocity, and acceleration. The vehicle information obtained from the sensors is then sent to a server located in the system infrastructure and stored in a database. The database generates CAMs from its stored data and broadcasts these from roadside transmitters. CAM-supported vehicles receive the CAMs and store the information in their LDMs following a reception procedure identical to that involved in the baseline CAM process (Proxy CAM), and receiver vehicles' ITS applications can access the data from this Proxy CAM.

In the following sections, we describe the system in detail by function.

To test the roadside system, it was implemented on Linux-based systems and evaluated in indoor and field tests.

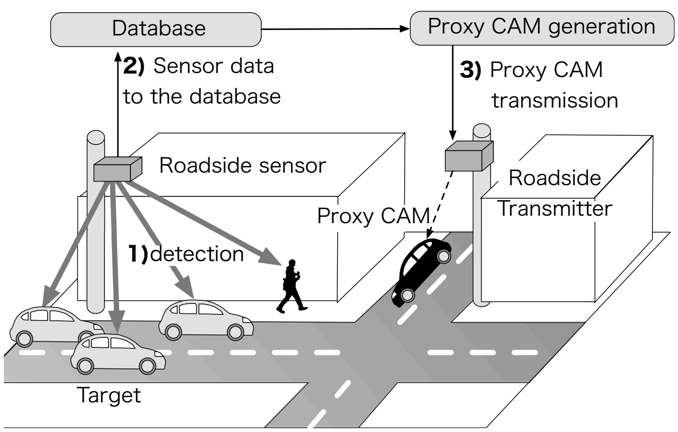

Figure 2. Overview of Proxy CAM

B. *Roadside Station for Proxy V2V Messaging*

Although Proxy CAM solves issues 1) and 2) in section II, issues 3), limited wireless range, and 4), malicious messaging, remain unsolved. In this section, we propose an additional functionality for the Proxy CAM roadside system to solve the all four issues.

1) Overview of proposed system: An overview of the proposed system is shown in Figure 3. In the system, roadside stations are installed at distributed locations, with each station detecting objects (vehicles, pedestrians, and bicycles) in the target area using sensors and wireless message receivers. The detected objects' information is stored in real-time in the database (a). Data processing includes malicious message detection through comparisons between sensor data and received V2V messages (b). The roadside station then advertises its proxy V2V messages from its database over ITS-dedicated media, sharing its dynamic information on the target area (c). The remote proxy messaging system delivers this dynamic information on demand using a cellular network such as LTE (d). Receiver vehicles can obtain this dynamic information from a combination of genuine and proxy V2V messaging and remote messaging. In this manner, fresh, dynamic information is available over a wider area.

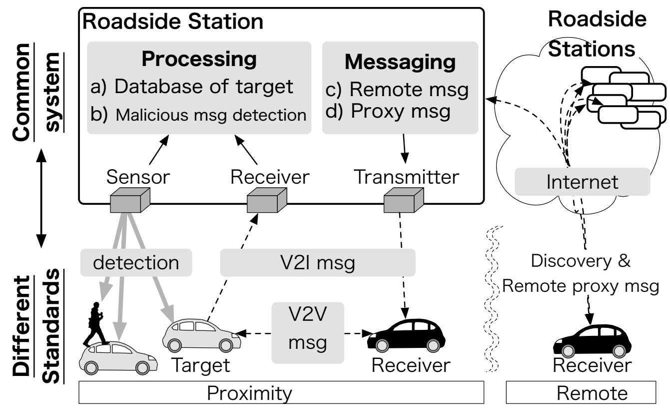

Figure 3. Roadside Station for Proxy V2V Messaging

2) Malicious message detection: Each roadside station detects target objects from both sensors and vehicle-sent V2V messages. The station can therefore check the correctness of received V2V messages by comparing their content with the sensor information during database processing (function b in Figure 3). If the location data (position, speed, direction) of the received message match the sensor data, the roadside sensor can trust that the information is correct and add the corresponding entry to the database. Data mismatching occurrences can follow two cases: 1) there are no V2V message data but there are sensor data at the location, or; 2) there are V2V message data but no sensor data at the location.

In the first case, if an object is in the target position of the sensor but no relevant V2V messages have been received, the system must add the object's information to the database. This is the normal procedure used in cases in which a vehicle is not equipped with a V2V transmitter. In the second case, if there is no object at the position indicated by a V2V message, it is highly likely that the message sender is disseminating false information. The system must therefore not include such data in its database and it must identify the sender as a malicious node. However, the manner in which malicious node alerts are sent to other nodes is outside the focus of this paper because, as mentioned in section IV-H, the dissemination of trusted information must be considered carefully for security reasons.

Conceptually, the roadside station regularly checks the consistency of physical space with cyber space and eliminates incorrect physical information projected to cyber space. To do so, the system must preferentially trust its sensor data over received messages data, following the principle generally used in connected autonomous vehicle systems.

3) Remote Proxy Messaging: A roadside station maintaining a database of dynamic information for its respective area can generate proxy informational V2V messages on behalf of target vehicles. Such messages are disseminated over the ITS media in addition to the flow of genuine V2V messages at, i.e., 760 Mhz in Japan, $5.8 \sim 5.9Ghz$ in the EU and United States. As illustrated in Figure 4, in Japan ASV messages are transmitted directly over ITS media. In the EU and United States, V2V messages are transmitted using transport and network layer technologies, namely, CAM, which is transmitted over the Basic Transport Protocol (BTP), and GeoNetworking (GN). In addition, BSM is transmitted over the WAVE Short Message Protocol (WSMP).

To overcome wireless range limitations, we apply remote proxy V2V messaging via roadside stations, as described above. To assess this scheme, we performed a preliminary evaluation using UDP/IPv6 over LTE in [21].

As shown in Figure 4, we propose remote proxy V2V messaging as a common solution usable by standards in Japan, EU, and the United States. We designed this system to use IPv6 for remote proxy V2V messaging because it fulfils cooperative ITS requirements as a result of its extended address space, embedded security, enhanced mobility support, and ease of configuration. The proposed system also uses UDP because this enables delivery of messages involving real-time data. Using UDP/IPv6, packets can be transmitted over general wireless media such as LTE, 3G, etc., in cases in which the delay is not too long for real-time data transmission.

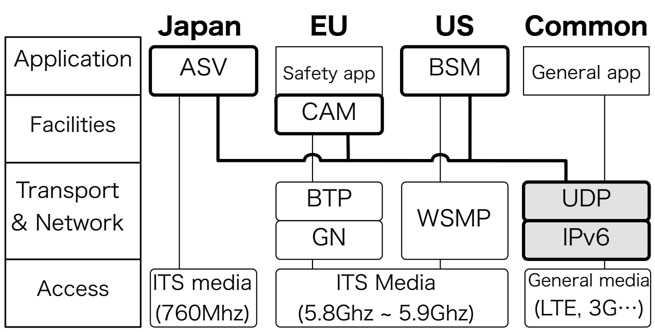

Figure 4. Remote Proxy V2V messaging

Remote proxy V2V messages are sent on-demand from vehicles arriving in a target area, e.g., an intersection, according to the requirements of the ITS application, e.g., a navigation system. The application requests dynamic information regarding future vehicle positions in advance. Note that, although IP address discovery of roadside stations is outside the focus of this paper, possible solutions for discovery include embedding IP addresses into the digital map, downloading static lists of IP addresses, or resolving the IPv6 address from geographical information using a DNS-like system [15], etc.

The remote proxy V2V messaging capability is considered to be an additional feature of the roadside station system. As such, vehicles arriving simultaneously at an intersection receive both proxy messages over the ITS media and remote messages over general media. Depending on the freshness of the data, the receiver side can then decide which data to use.

IV. Requirements for the solution

In this section, we analyse the design requirements for the roadside-assisted V2V messaging.

A. Coexistence with the CITS Standards

To enable interoperability among countries, a cooperative ITS (CITS) must be developed based on universal architecture, protocols, and technologies. Such a solution must adopt techniques for standardized V2V messages such as CAM in the EU, BSM in the United States, and ASV in Japan. Facilities layer functionalities are of particular importance in ITS Station architecture because applications developed in the architecture access functions via a standard API; correspondingly, any solution for interoperability must not require extensions such as an LDM to the facilities layer.

B. Sensor independence

The solution proposed in this paper uses roadside sensors to obtain vehicle data within the target area with regard to, e.g., position and the velocity. Many types of sensors can be applied in this manner, including image sensors, LiDAR, induction loops, infrared sensors, and microwave radar. However, the implementation should not depend on a particular type of sensor because sensor requirements will vary by environment and purpose, e.g., urban environments or highways and budget or policy drivers. To enable versatility, therefore, roadside assisted V2V platform should support many types of sensors.

C. Distributed sensors

Sensors may be installed in multiple distributed locations to obtain wider coverage depending on need. For example, sensors may be placed to obtain real-time data from many vehicles in an urban scenario or traffic jam. Any implemented solution must have the capacity to handle large real-time data from distributed sensors.

D. Optimized Transmission Coverage

Depending on its configuration, a roadside system must be able to handle installation of multiple transmitters in distributed locations to cover a wider transmission range. It is necessary to consider strategic placement of transmitters, possibly employing message dissemination strategy algorithms for determining, for example, frequency use, message ordering, and area determination, to enable multi-transmitter scenarios. Moreover, the roadside system must be aware of the V2V messaging capabilities of target vehicles to eliminate duplicate message delivery via the genuine and proxy V2V messaging systems. The system must also estimate the original message delivery area and transmit proxy messages to the wider area not reached by the original message transmission.

E. Multi-path Message Delivery

Genuine V2V messaging provides the most accurate real-time dissemination of information on target vehicles; however, it is susceptible to the four problems described in Section II. Proxy V2V messaging is efficient in cases in which the target vehicle does not have V2V sender functionality. However, its wireless coverage is limited. Remote V2V messaging can deliver dynamic messages anywhere, although with deteriorating latency. Correspondingly, the receiver should be able to combine genuine V2V messaging, proxy V2V messaging, and remote V2V messaging functionality into a combined functionality.

F. Real-time delivery of messages

Frequent transmission of V2V messages allows for the tracking of highly dynamic vehicle status information such as position, velocity, and acceleration. Genuine CAMs, for example, are transmitted 1$\sim$10 times per second. A solution should also send dynamic vehicle information frequently. Overall, delays in message sensing and transmission must be minimized.

G. Scalability

In typical urban scenarios or traffic jams, a few hundred vehicles will occupy the target area of a roadside station. The generation of proxy V2V messages to and from hundreds of vehicles ten times per second can cause serious interference, leading to the potential dropping off of several hundred potential remote V2V message receivers with interest in the target area dynamic information. To avoid communication congestion, the solution must transmit dynamic information efficiently to allow for a scalable system.

H. Security Consideration

There are three security considerations relating to the proposed scheme. The first is how to maintain information on vehicles sending incorrect information as detected by the malicious message detection system. A trust model for information dissemination is necessary. Because roadside stations will be operated by public agencies, malicious node information can be shared with the public by such authorities. However, more consideration would be necessary in sharing such information with other administrative domains. Second, the V2V system was designed to send "I am here" messages. However, using proxy messaging changes the scheme to "he is there" messaging. Any potential security concerns arising from this introduction of proxy messaging should therefore be carefully analyzed. Third, the roadside stations send dynamic information via the Internet instead of by V2V single-hop broadcasting. Thus, messages must be encrypted between the roadside station and the requested vehicle to protect their data against tapping and falsification.

V. Related works

the Japanese Metropolitan Police Department developed the Driving Safety Support Systems (DSSS) as an infrastructure assisted CITS for accident reduction [9]. DSSS tested three experimental systems: a rear-end collision prevention system for use upon entering traffic jams in which the car is positioned in front of protective obstacles; a collision prevention system for use when turning right at intersections; and a collision prevention system for use at intersections with poor sight lines. Infrastructure-assisted CITS using beacons and FM broadcasting have been implemented on highways across Japan.

It has been shown that the performance of Vehicular Ad-Hoc Networks (VANETs) depends on the transmission power, frequency of transmission, and the V2V and V2I message lifetimes [30]. In turn, it is understood that the performance of V2V and V2I messages depends strongly on the link quality and the propagation conditions [13]. [13] demonstrated that awareness levels for V2I communication are better than those for V2V communication if roadside units are located in an advantageous manner. [13] also explained that transmission power is more important than frequency of transmission in V2X communication.

[24] demonstrated how multi-sensor data fusion can leverage consistency and plausibility checking for perception sensor data. In particular, the contents of CAMs as delivered by connected vehicles with on-board perceptions sensors can be independently validated.

A wide variety of sensing modes can be implemented for use in road traffic. Vision-based vehicle detection and tracking techniques are summarized in [28]. Millimeter-wave radar and cameras are important equipment for sensing vehicles using vision-based systems. Millimeter-wave radar can also be used for measuring target range and speed, as is currently done by police in traffic speed regulation [28]. Furthermore, millimeter-wave radar can be used under poor viewing conditions in bad weather. Stereo cameras are another very effective method for sensing vehicles. Such cameras can sense both a vehicle position and velocity [11].

One approach to creating messages for sharing object perceptions relayed from sensors is Cooperative Perception Messaging (CPM), which is specified in Ko-PER as a method for sharing perceived dynamic objects in equipped vehicle or roadside station environments [26][27]. Environmental Perception Messaging (EPM) uses proprietary messages that contain lists of all perceived objects and carry unique IDs for vehicles registered by local perception sensors [17][16] Sensory Observation Messaging (SOM) is a proposed method for sharing infrastructure sensor information with potentially vulnerable road users [12].

Cloud-based cooperative awareness between vehicles and pedestrians was proposed in [10]. Under the scheme, pedestrians repeatedly send their positions to the cloud from their smartphones, allowing the cloud to alert vehicles to the approach of pedestrians. Vehicle-to-Pedestrian (V2P) communication was also investigated in [23], who proposed a scheme in which pedestrians receive CAMs on their smartphones from vehicles hidden behind obstacles.

In the field of cooperative autonomous driving, [22] introduced a method of occupancy grid map merging dedicated to multivehicle cooperative local mapping purposes in outdoor environments. [18][19] proposed a multimodal cooperative perception system that provides see-through, lifted-seat, satellite, and all-around views to drivers. The features of the system were validated in real-world experiments involving four vehicles sharing a road.

Traffic lights have long been used to coordinate traffic flows at intersections. To update traffic management to the connected autonomous vehicle age, [14] proposed autonomous intersection management in which vehicles coming to an intersection connect to a dedicated intersection controller that schedules transfer through the intersection. [25] extended the priority-based coordination approach at an intersection to support both autonomous and legacy vehicles.

VI. Conclusion and Future work

We have found that the V2V messaging standards in the EU, US, and Japan all suffer from four general shortcomings. To overcome these, we proposed a roadside-assisted V2V messaging system. The proposed system is a real-time cyber-physical system that integrates sensing technology with V2V and V2I networks and combines ITS and cellular media with IPv6 to disseminate dynamic, fresh information to a wider area. The proposed system also presents a common solution for differing national and regional standards, such as those in the EU, US, and Japan, as it is independent of any specific standards. We further analyzed the potential requirements for designing a specification for roadside-assisted V2V messaging.

In future work, we will need to fully implement the proposed system and validate it in field operational tests. We are also planning to evaluate the large-scale performance of the system using simulation. In the development of the fifth-generation mobile network (5G), mobile edge computing will play an important role in achieving ultra-low latency between V2V messaging. Because edge stations must be located in positions with good visibility such as intersections if they are to cover wider areas, our aim is to ensure that the proposed roadside system has high technical compatibility needed to co-locate with 5G edge stations. To this end, further study on the integration of 5G systems will be necessary.

Acknowledgment

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