applied sciences

MDPI

Article

Topological Sequence Recognition Mechanism of Dynamic Connected Cars Using the Connected Mobile Virtual Fence (CMVF) System for Connected Car Technology

Young Hyun Eom [1], Gyowoong Hwang [2], Minsu Lee [2], Young Geun Choi [1,*], Sungkuk Cho [3,*], R. Young Chul Kim [4,*] and Byungkook Jeon [2,*]

1 Department of Computer Software, Kwangwoon University, Seoul 04066, Korea; class76@kw.ac.kr
2 Department of Software, Gangneung-Wonju National University, Wonju-City, Gangwon Province 26403, Korea; hky5399@naver.com (G.H.); minsuuuus@naver.com (M.L.)
3 Department of Multimedia Engineering, Gangneung-Wonju National University, Wonju-City, Gangwon Province 26403, Korea
4 Department of Software and Communication Engineering, Hongik University, Seoul 04066, Korea
* Correspondence: ygchoi@kw.ac.kr (Y.G.C.); skc899@gwnu.ac.kr (S.C.); bob@hongik.ac.kr (R.Y.C.K.); jeonbk@gwnu.ac.kr (B.J.); Tel.: +82-2-940-5651 (Y.G.C.); +82-33-760-8685 (S.C.); +82-44-860-2477 (R.Y.C.K.); +82-33-760-8705 (B.J.)

Received: 15 May 2020; Accepted: 23 June 2020; Published: 24 June 2020

Abstract: To prevent traffic accidents, even autonomous vehicles, as well as connected cars, need to know the driving situation of other vehicles in the vicinity. In particular, in emergency situations, messages' transmission among vehicles can face many problems such as the broadcast storm, message flooding, or message contention. Therefore, this paper proposes a topological sequence recognition mechanism that calculates the driving direction of vehicles, the geographical location and relative position associated with the driving direction, and the relative safety distance for each vehicle in connected subgroups of connected cars using the Connected Mobile Virtual Fence (CMVF) system. Thus, the proposed mechanism can alleviate issues with message dissemination as a vehicle will know the driving situations of other nearby vehicles. In addition, the proposed mechanism is found to be very effective, particularly in preventing secondary accidents due to traffic accidents in front of the vehicle so that emergency messages can be disseminated to the trailing vehicles. Finally, it is expected that the proposed mechanism will be reflected in the technology of connected cars and autonomous vehicles.

Keywords: topological sequence recognition mechanism; Connected Mobile Virtual Fence (CMVF) system; broadcast storm; connected car; autonomous vehicle; Vehicle to Everything (V2X)

1. Introduction

Thus far, many studies and simulations to realize connected car technology have been actively conducted [1–3]. Connected car technology based on vehicle-to-everything (V2X) communication must be connected to other vehicles, objects, and people, but is composed of partially connected subgroups according to temporal and geographical influences such as time, location, and wireless network coverage [4]. If such a subgroup is not configured, all vehicles will broadcast messages containing their state such as vehicles' information, driving record, and path history every 10 microseconds according to European Telecommunications Standards Institute (ETSI) recommendations [5].

However, when such a broadcasting is executed, serious problems such as the broadcast storm [4,6], message flooding [7], or message contention occur [8]. To solve these problems, most studies had been proposed and implemented vehicular ad-hoc networks (VANET)-based message dissemination, message multi-hopping, and message relay algorithms [9,10]. Ghazi et al. not only classified and reviewed some recent contributions to emergency message dissemination in vehicular networks but also discussed various proposed methods for emergency message dissemination based on the Intelligent Transport System (ITS), Internet of Things (IoT), Priority messaging, Clustering approach, Software-Defined Network (SDN), and Fog computing [9]. The work in Reference [4] studied the integration of emergency messages for connected cars. Thakur et al. proposed a real-time solution for traffic management by calculating the density of traffic on the roads, and high priority is given to a lane where emergency vehicles can travel [11]. The mechanism introduced by Reference [12] includes a smart real-time traffic monitoring system that monitors traffic statistics on a daily and weekly basis and works on early detection of an incoming emergency vehicle. Sumi et al. presented an approach for smart cities by integrating the concept of IoT and VANET to control the traffic lights and ease the movement of ambulances in cities [13]. In Reference [14], Younes et al. introduced a dynamic scheduling algorithm for traffic signal timing. Tian et al. proposed a protocol based on the position for broadcasting emergency messages in VANETs, and the disseminated messages are broadcasted to reduce road accidents [15]. The scheme of multi-hop clustering-based emergency message dissemination (MC-EMD) introduced by Reference [16] makes clusters of different neighboring vehicles, and the messages are sent to all clusters that are a bit far from the risk zone to avoid both network and traffic congestion. In Reference [17], the authors carried out performance modeling for emergency message dissemination using priority in VANET. Suthaputchakun et al. proposed a multi-hop message broadcast scheme, so-called the trinary partitioned black-burst-based broadcast protocol (3P3B), for time-critical emergency services in VANET [18]. In addition, there are many papers that present emergency message dissemination schemes based on congestion avoidance in VANET [19–21].

On the other hand, in non-line-of-sight (NLOS) situations, critical traffic situation information from the preceding vehicles needs to be transmitted to the following vehicles in order to avoid accidents. In cases of emergency situations such as traffic accidents involving preceding vehicles, having the preceding vehicles transmit the emergency message with priority to the following vehicles is the best approach to prevent secondary accidents. However, there are few studies to distinguish between vehicles in front of or behind the current vehicle, even within a subgroup of connected cars. [22,23]. Studies on the changes in the dynamic topology due to frequent overtaking caused by variations in the speeds of vehicles are also scarce. In addition, there are many differences in the results of realistic load testing among most related papers, as they are very theoretical and rely on several network simulation tools to predict the results [9].

Therefore, this paper proposes a topological sequence recognition mechanism for forming connected car-based subgroups and recognizing the relative sequence and distance according to the dynamic topology changes of the preceding or following vehicles for each vehicle in subgroups. The experimental procedure to configure subgroups of connected cars in this paper uses the Connected Mobile Virtual Fence (CMVF) system, which has been researched and developed in advance and supports vehicle-to-vehicle (V2V) communication [4,10]. In the CMVF system, the CMVF client is installed in each smartphone, and each smartphone is mounted in a vehicle. Thus, for the purposes of this paper, it is assumed that the CMVF client is the same as the vehicle.

The topological sequence recognition mechanism proposed herein calculates the driving direction of vehicles within a subgroup of connected cars, the geographical location and relative position associated with the direction, and the relative safety distance of each vehicle. The proposed mechanism to improve the CMVF system comprises three algorithms that detect the dynamic topology changes of vehicles in terms of sequence and position in the current subgroup during driving, and determine whether a vehicle is located at the front, middle, or rear. The information that the driving vehicle itself is aware of regarding the sequence is a very important criterion for disseminating driving information messages, and in some cases, it can prevent problems such as the broadcast storm, message flooding, or message contention. The reason is that if any vehicle in a subgroup has an accident and all vehicles know their position in the sequence, preceding vehicles need not receive the emergency message; the message only needs to be transmitted to the following vehicles. In addition, the proposed mechanism applies to only an arbitrary subgroup of connected cars, but the same mechanism is also applied to recognize the geographical location and relative position of all vehicles among subgroups.

In the near future, it is expected that the proposed mechanism will be implemented in the technology of connected cars and autonomous vehicles to help realize more efficient message dissemination and a safer transportation environment.

The remainder of the paper is structured as follows. Section 2 introduces the CMVF system briefly and proposes a topological sequence recognition mechanism. Section 3 describes and evaluates the results of actual road driving experiments to verify the three algorithms proposed in the previous section. The last sections present the discussion and conclusions.

2. Materials and Methods

2.1. Overview of the Existing CMVF System

The CMVF system, which was developed in advance, is essentially a context-awareness system consisting of the CMVF server and client to provide context-aware services [10,22]. The CMVF server performs the role of an ITS, and the CMVF client using a smartphone acts on behalf of a vehicle [10]. Thus, a smartphone itself, instead of attaching additional devices to existing vehicles, becomes an independent CMVF client; it maintains a dynamic awareness radius that senses and reacts according to the vehicle's speed, which allows context-aware computing within its virtual boundary [10,24]. Thus, vehicle-to-vehicle (V2V) communication occurs when vehicles with attached smartphones as CMVF clients are connected to clients of other vehicles through mutual awareness [4,24]. The mutual awareness mechanism already developed is implemented by exchanging integrated messages among CMVF clients based on context-aware computing [24]. Here, integrated messages composed by the integrated messages framework, which was designed earlier, are added with context-aware information of CMVF clients after comparing and analyzing common fields of Basic Safety Message (BSM) and Cooperative Awareness Message (CAM)/Decentralized Environmental Notification Message (DENM) [25–28].

Therefore, this paper adds the following functions to improve the existing CMVF system. First, the exact cardinal direction of the smartphone is determined using the topological difference between latitude and longitude. Second, a representative heading direction for subgroups of connected cars is determined using the exact cardinal direction proposed in the first step. This is because connected cars move in the same direction, and if the movement direction is known, the sequence can be determined according to the differences in latitude and longitude of vehicles. Third, the topological sequence of each vehicle is determined within a subgroup of connected cars.

Further details and algorithms for these three functions are presented in the following sections.

2.2. Determination of the Cardinal Direction

Smartphones use a combination of the azimuth, pitch, and roll to calculate cardinal directions. However, this combination has the disadvantage of being excessively sensitive, as the azimuth constantly changes due to slight shaking even though the smartphone is moving in a certain direction. In addition, the azimuth sensor also has a distortion phenomenon according to surrounding structures and geomagnetic distribution, and measures the most accurate value when parallel to the ground. The main causes are the influence of the surrounding metal structures and the tilt of the azimuth. However, as the user is not always horizontal when the user holds the smartphone, distortion occurs due to the inclination of the smartphone [29,30]. Therefore, the determination of the direction angle using the azimuth sensor is unsuitable for determining the geographic or topological sequence of connected cars. However, orientation determination using only latitude and longitude can yield a very accurate directional state. Thus, this paper proposes

Algorithm 1 (derived from Table 1) to determine the cardinal direction using topological differences in latitude and longitude.

Table 1. Factors and cases for determining the exact cardinal direction.

Factor Case	1	2	3	4	5	6	7	8
Latitudes' difference	0	0	+	−	+	+	−	−
Longitudes' difference	+	−	0	0	+	−	+	−
The determined direction	**E**	**W**	**N**	**S**	**NE**	**NW**	**SE**	**SW**

(where E: East, W: West, N: North, S: South, NE: NorthEast, NW: NorthWest, SE: SouthEast, SW: SouthWest, +: Positive value, −: Negative value).

Table 1 lists two factors for determining the cardinal direction, and the cardinal directions in eight cases. The differences in latitudes and longitudes follow Equations (1) and (2).

$$ {}_{\text{difference}}\text{Latitude} = {}_{\text{current}}\text{Latitude} - {}_{\text{before}}\text{Latitude} \quad (1) $$

$$ {}_{\text{difference}}\text{Longitude} = {}_{\text{current}}\text{Longitude} - {}_{\text{before}}\text{Longitude} \quad (2) $$

In Equation (1), ${}_{\text{difference}}\text{Latitude}$ is the difference between ${}_{\text{current}}\text{Latitude}$ (latitude value of the current location) and ${}_{\text{before}}\text{Latitude}$ (latitude of the before location), and Equation (2) follows the same principle. The cardinal direction is also determined by whether the difference is positive or negative in the eight cases. Taking case 5 in Table 1 as an example, if a vehicle moves in the northeast direction, both latitude and longitude increase, so if the differences in latitude and longitude are positive, the cardinal direction is identified as northeast. Algorithm 1 indicates this process.

Algorithm 1 Determining the cardinal direction

```
/* Input: currentLatitude, currentLongitude, beforeLatitude, beforeLongitude */
BEGIN
    IF beforeLatitude = 0 and beforeLongitude = 0 THEN RETURN terminate
    ENDIF
    differenceLatitude ← currentLatitude – beforeLatitude
    differenceLongitude ← currentLongitude – beforeLongitude
    IF differenceLatitude = 0 and differenceLongitude = 0 THEN
        heading ← the azimuth angle by sensor
    ELSE
        heading ← updateDirection(differenceLatitude, differenceLongitude)
ENDIF
IF differenceLatitude > 0 and differenceLongitude = 0 THEN heading ← N
ELSE IF differenceLatitude < 0 and differenceLongitude = 0 THEN heading ← S
ELSE IF differenceLatitude = 0 and differenceLongitude > 0 THEN heading ← E
ELSE IF differenceLatitude = 0 and differenceLongitude < 0 THEN heading ← W
ELSE IF differenceLatitude > 0 and differenceLongitude > 0 THEN heading ← NE
ELSE IF differenceLatitude > 0 and differenceLongitude < 0 THEN heading ← NW
ELSE IF differenceLatitude < 0 and differenceLongitude < 0 THEN heading ← SW
ELSE IF differenceLatitude < 0 and differenceLongitude > 0 THEN heading ← SE
ENDIF
RETURN heading
END
```

Algorithm 1 determines the cardinal direction using the values of the variables ${}_{\text{current}}\text{Latitude}$, ${}_{\text{current}}\text{Longitude}$, ${}_{\text{before}}\text{Latitude}$, and ${}_{\text{before}}\text{Longitude}$ when the location on the global positioning system (GPS) sensor in the smartphone changes. Each value of the variables ${}_{\text{before}}\text{Latitude}$ and ${}_{\text{before}}\text{Longitude}$ is changed after the 0.2 s sleep condition in which each current latitude and longitude are measured, and this measured value is replaced by the preceding values of latitude and longitude. In Algorithm

1, if a value of either of the variables $_{\text{before}}$Latitude or $_{\text{before}}$Longitude is zero, the algorithm is stopped; otherwise, the differences in the values of the latitudes and longitudes are obtained. If the two differences are 0, it indicates that there is no change in location, and therefore, the direction of the azimuth sensor of the smartphone is accordingly updated. The next step obtains the heading direction by the following Algorithm 2, which determines the direction of vehicles based on the difference in the values of the latitudes and longitudes estimated by Algorithm 1.

2.3. Determination of the Representative Heading Direction for Connected Cars

The previous section presented the method for determining the cardinal direction using the smartphone inside a vehicle. This section describes the mechanism for determining the representative heading direction for subgroups of connected cars by obtaining the directions estimated from multiple smartphones in the previous section. The reason for determining the heading direction of the subgroup of connected cars is illustrated in Figure 1.

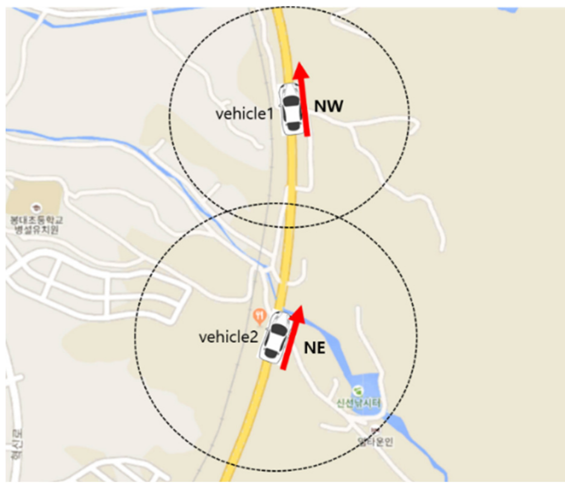


Figure 1. Situation for same driving directions but different headings.

As illustrated in Figure 1, the two connected cars are moving in the same direction, but vehicle 1 is heading in the northwest (NW) direction, and vehicle 2 in the northeast (NE) direction. The driving direction should be the same for both vehicles in this connected group. However, as the headings differ, a representative heading direction must be designated to determine the sequence of the vehicles.

Therefore, in this section, four cardinal directions are determined by analyzing the headings of the connected cars, as presented in Table 2.

Table 2. Estimation of the representative heading direction of the connected cars.

Heading Direction	E	W	S	N
E	**1**	0	0	0
W	0	**1**	0	0
S	0	0	**1**	0
N	0	0	0	**1**
SE	**1**	0	**1**	0
NE	**1**	0	0	**1**
SW	0	**1**	**1**	0
NW	0	**1**	0	**1**

In Table 2, Direction refers to the representative direction for the subgroup of connected cars, and Heading refers to the cardinal direction of each connected car. As an example, for a sequence of a connected car group with the east direction, 'E,' 'SE,' or 'NE' are marked as 1. The algorithm used for this method is as follows.

Algorithm 2 Determining the representative heading direction

```
/* Input: v ← A list of connected cars */
BEGIN
    Initialize eastCount, westCount, southCount, northCount to 0
    FOR i = 0 to size of v
        IF v contains 'E' THEN eastCount++     ENDIF
        IF v contains 'W' THEN westCount++    ENDIF
        IF v contains 'S' THEN southCount++    ENDIF
        IF v contains 'N' THEN northCount++    ENDIF
    ENDFOR
    IF eastCount >= 2 THEN headingDecision ← "EAST"
    ELSE IF westCount >= 2 THEN headingDecision ← "WEST"
    ELSE IF southCount >= 2 THEN headingDecision ← "SOUTH"
    ELSE IF northCount >= 2 THEN headingDecision ← "NORTH"
    ELSE headingDecision ← "NONE"
    ENDIF
    RETURN headingDecision
END
```

In Algorithm 2, the heading of the connected cars represents the number of vehicles heading in the east, west, north, and south. If the value of each count variable is 2 or more, it means that vehicles are connected and driving in the same direction, and therefore, the corresponding direction is determined as representative.

2.4. Determination of the Topological Sequence of Connected Cars

This section describes an algorithm for determining the topological sequence of each vehicle within a subgroup of connected cars, using the representative direction of vehicles determined in Section 2.3. After the representative direction of the connected cars has been determined, the topological sequence needs to be determined based on the values of latitude and longitude and the representative heading directions. For example, if the representative direction is "NORTH," a vehicle with high latitude is located at the front. The algorithm used can be described as follows.

Algorithm 3 Determining the topological sequence of connected cars

```
/* Input: v ← A list of connected cars, and headingDecision */
BEGIN
    orderingMessage ← Array of device id, latitude, and longitude of v
    IF headingDecision = "EAST" THEN sort in descending order by longitude
    ELSE IF headingDecision = "WEST" THEN sort in ascending order by longitude
    ELSE IF headingDecision = "SOUTH" THEN sort in ascending order by latitude
    ELSE IF headingDecision = "NORTH" THEN sort in descending order by latitude
    ENDIF
    RETURN orderingMessage
END
```

2.5. Analysis of the Algorithms

The time complexity of all the proposed algorithms is analyzed as follows.

As Algorithm 1 performs only simple arithmetic operations, the time complexity is O(1). Algorithm 2 repeats as many as the number of input connected cars so that the time complexity is O(n). Finally, Algorithm 3 is O(n log n) because it is sorted using the Quick sort algorithm. Therefore, the overall time complexity of the proposed mechanism is O(n log n).

3. Results

To verify the three aforementioned algorithms proposed in Section 2, we performed actual road driving experiments and repeated them several times. In these experiments, four Samsung Galaxy smartphones installed with the CMVF client were equipped on each vehicle, and the vehicles were driven by reciprocating on the red line path, which was a one-way two-lane road (14 km), as shown in the map of Figure 2. The device-IDs of each smartphone were as follows: fce77f9031108d9e(abbr. A), b0af188f450aec18(abbr. B), 55163c6c125b123b(abbr. C), and bcbd7edce58f640c(abbr. D).

Figure 2. Driving map for vehicles.

First, all the four vehicles were made to move without connecting them to one another, and the initial screen of each of the four independent CMVF clients are shown in Figure 3. In each of these screens, the shaded area on the upper left shows the topological sequence of all connected vehicles when connected, and at the bottom of the map, driving information of each vehicle such as device-ID and the current time, latitude, longitude, speed, radius as awareness range, and the heading direction is provided. In addition to these basic attributes, various other attributes such as CAM/DENM and BSM specification can also be provided, which are beyond the scope of the present work [27,28]. Furthermore, it can also be observed from Figure 4 that the topological sequence of these vehicles appear to be in the following logical sequence: B→A→D→C; however, these vehicles are not aware of each other's relative position, as they are not connected. In addition, each dashed circle surrounding the vehicles represents the speed-reactive awareness range by the CMVF client. Outside this area, a time mismatch of roughly 1–2 s appears on the smartphone screens. This mismatch between the smartphones can be attributed to the internal time latency of the smartphones, transmission delay of the wireless mobile network, server processing latency, and so on. However, this paper considers that the absolute time of each smartphone is the same as real time.

After a certain period, the two screens depicted on the top in Figure 5 show that vehicle B (device-Id: b0af188f450aec18) is increasing to form a connected group with vehicle A (device-Id: fce77f9031108d9e). In other words, while the speed of vehicle B in Figure 3 is approximately 58.26 km/h at 16:03:07, it increased to approximately 68.47 km/h at 16:03:22, as can be seen on the bottom of Figure 5. Accordingly, the radius of the area indicating mutual awareness for communicating with other vehicles also increased from 34 to 39 m. Here, the blue and red boxes indicate the driving information of our own and other vehicles, respectively, when the two driving vehicles are connected to one other. In addition, the upper left side of each screen shows the topological sequence of each vehicle in the current connected group. In other words, the triangle in the upper left side of the screen indicates that vehicle B is geographically located behind vehicle A, whereas the circle indicates that vehicle A is driving ahead of vehicle B. Therefore, the two vehicles recognize each other's relative positions and simultaneously gather the geographical location of one another in the connected group; this situation is conceptually expressed on the left side in Figure 6.

After a duration of one minute, a situation occurred wherein vehicle B increased its speed and overtook vehicle A. At this point in time, the speed of vehicle B shown at the bottom of the two screens in the lower subfigures of Figure 5 was found to increase from a value of approximately 68.47 to 75.73 km/h, and the speed of vehicle A was also found to increase from approximately 57.25 to 66.73 km/h. Therefore, the sequence of vehicles shown within the red triangles and circles in the upper left of the screens indicates that both vehicles are geographically aware that vehicle B is ahead of vehicle A. A conceptual illustration for this change in topological sequence is shown on the right side of Figure 6.

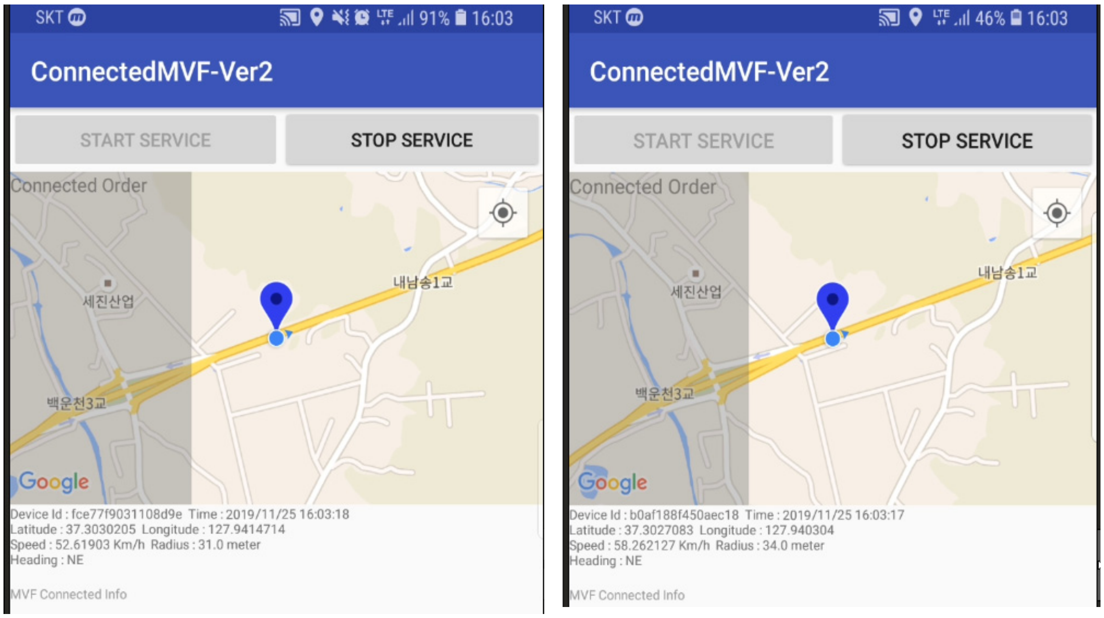
Similar to the situation illustrated in Figures 5 and 6, Figures 7 and 8 show the formation of a subgroup in which vehicles D (device-Id: bcbd7edce58f640c) and C (device-Id: 55163c6c125b123b) are connected and the situation wherein vehicle D overtakes vehicle C. The two screen images on the top in Figure 7 show that, initially, the two vehicles are connected and can recognize one another (information within the red rectangles at the bottom of the screens); further, on the upper left areas of the screens, the circles and triangles contain information on the current geographic sequence between the two recognized vehicles. The illustrations on the right in Figures 7 and 8 express the recognition of the topological sequence of the two vehicles in the group due to the change in speed of vehicles D and C.

The following experiment shows the result of forming a subgroup in which three vehicles are connected, and then recognizing the sequence among them. The screens (C), (B), and (A) in Figure 9 show the situation wherein vehicle C that was trailing was accelerated and included into the preceding connected subgroup, which comprised vehicles A and B, as shown in Figure 5. However, vehicle D was separated from the subgroup in Figure 7. Here, vehicle C exchanges its driving information with the preceding vehicle B and recognizes its own topological sequence. However, because vehicle B has all the driving information about the preceding vehicle A and the succeeding vehicle C, the upper left portion of the screen in vehicle B contains all the topological sequences of other vehicles including itself. In addition, that of the screen in vehicle D shows that the connected group disappears, and only its own driving information is displayed. The topological sequence for these events is shown in Figure 10.

As the final case of the experiment, after a certain period of time, the results showed that all four vehicles participating in the experiment formed a fully connected group; further, the results indicated the relative position of all vehicles by recognizing the topological sequence of vehicles within the connected group. The images of screens displaying the results are shown in Figures 11 and 12. As shown in Figure 11, the topological sequence of all vehicles shown on the upper left of all screens indicated A→D→B→C, and the geographical location of all vehicles was also the same. The illustration for this sequence is shown in Figure 12. In addition, as the boxes at the bottom of each screen of Figure 11 showed the formation of a fully connected group, the driving information of other vehicles including its own appeared for each vehicle at the same time. Therefore, each vehicle knows which vehicle is ahead and which is behind in the current group.

Most vehicles run at a constant speed on the road, but they often overtake other vehicles by accelerating to overcome any delay or to avoid traffic congestion. It is important for autonomous vehicles to gauge the geographic location on the road with respect to the surrounding vehicles even when a situation of departure from the current sequential vehicle group occurs. The necessity to know the situation of preceding vehicles is to prevent vehicle accidents while overtaking.

Figures 13 and 14 show that vehicles in the connected group recognize each other by incorporating an overtaking situation's information. As shown in Figures 13 and 14, after approximately 3 min had elapsed from the current time in each vehicle shown in Figure 11, vehicles A and D accelerated, and their speeds surpassed those of vehicles B and C. Here, if an overtaking situation occurs, the topological sequence of all vehicles should also be changed and recognized. The upper left parts of each screen image in Figure 13 show that the sequence information among vehicles is correctly reflected from the previous sequence A→D→B→C to sequence B→A→C→D.



A B

Figure 3. Initial screens of the independent Connected Mobile Virtual Fence (CMVF) clients in the four vehicles.

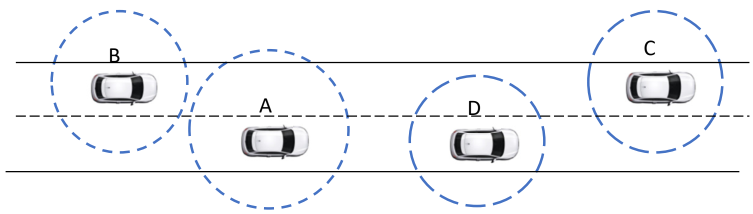


Figure 4. Illustration of the current topological sequence of each vehicle.

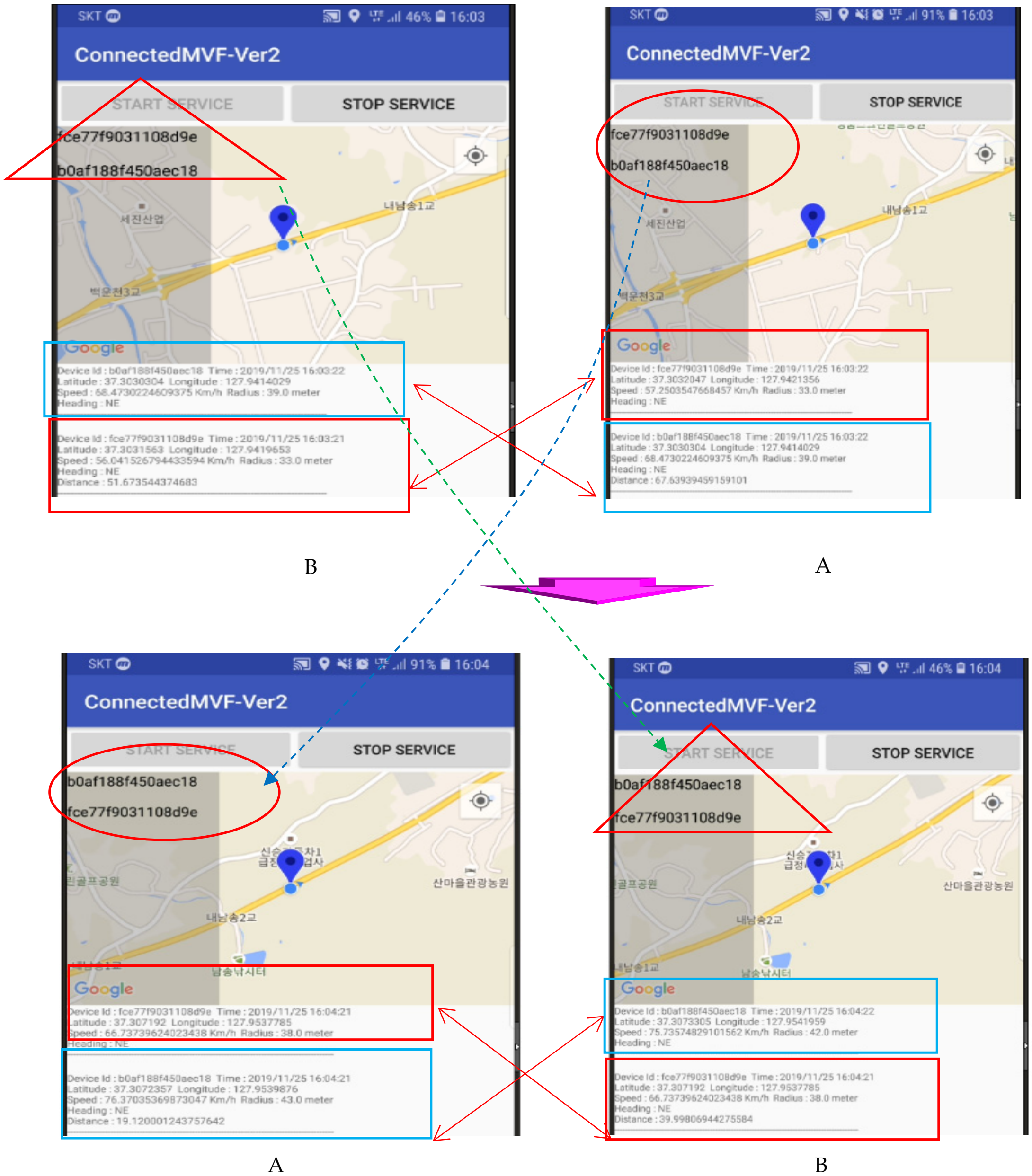


Figure 5. Screen images showing when a connected group is formed and when overtaking occurs.

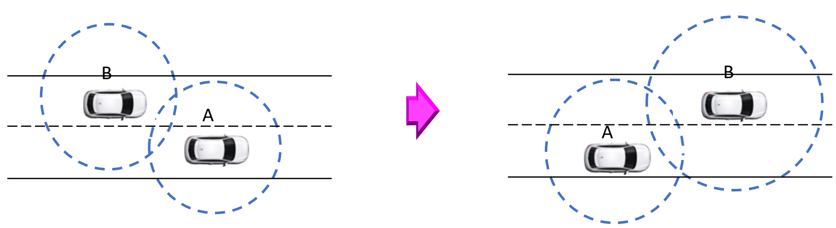


Figure 6. Conceptual illustration of the topological vehicle sequence shown in Figure 5.

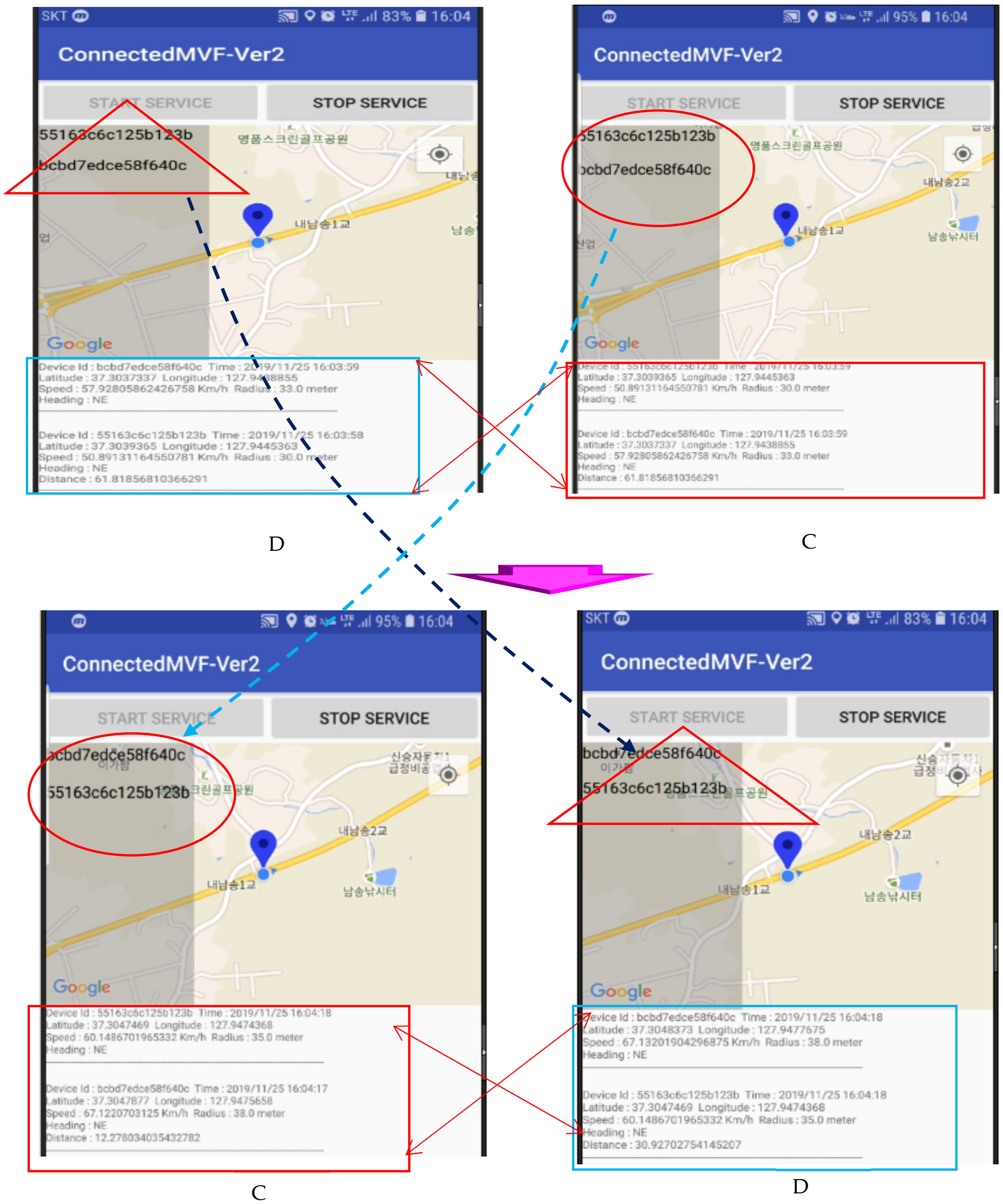


Figure 7. Screen images of when a connected group is formed (top) and when overtaking occurs (down).

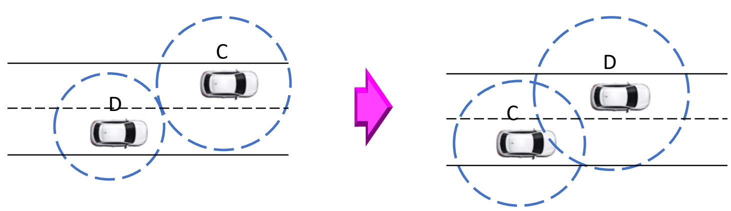


Figure 8. Conceptual illustration of the topological vehicle sequence shown in Figure 7.

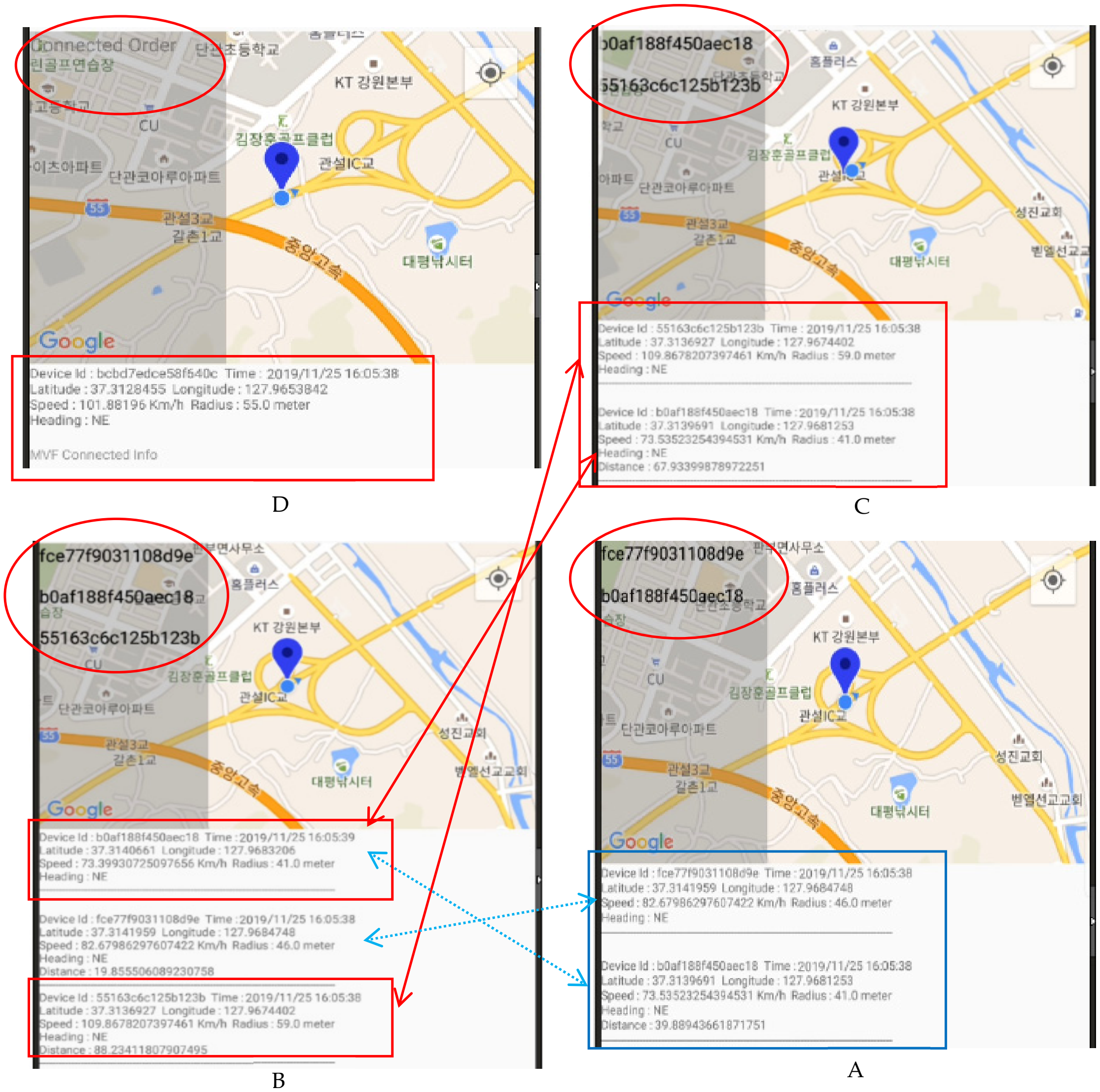


Figure 9. Screen images of the connected group's reformation and overtaking.

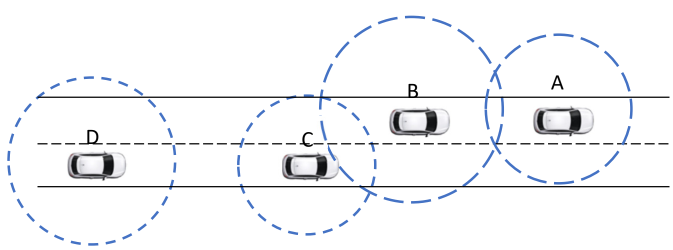


Figure 10. Conceptual illustration of the topological vehicle sequence shown in Figure 9.

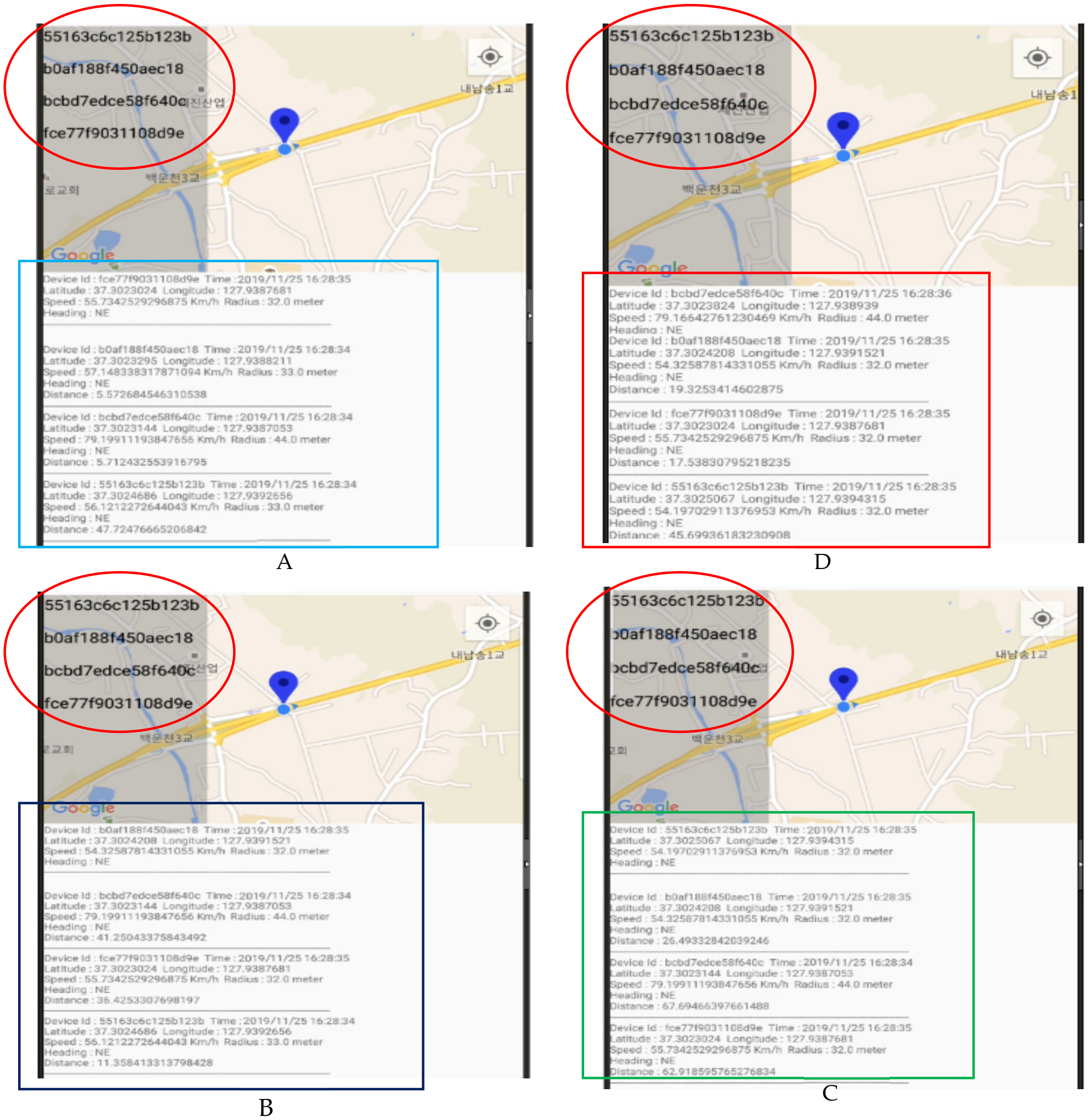


Figure 11. Screen images showing the formation of a fully connected group and the sequence of all vehicles.

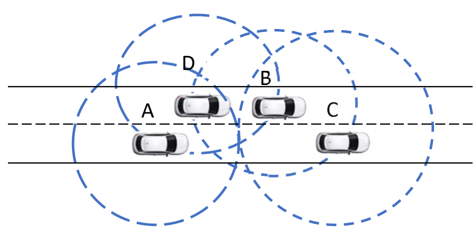


Figure 12. Conceptual illustration of the topological vehicle sequence shown in Figure 11.

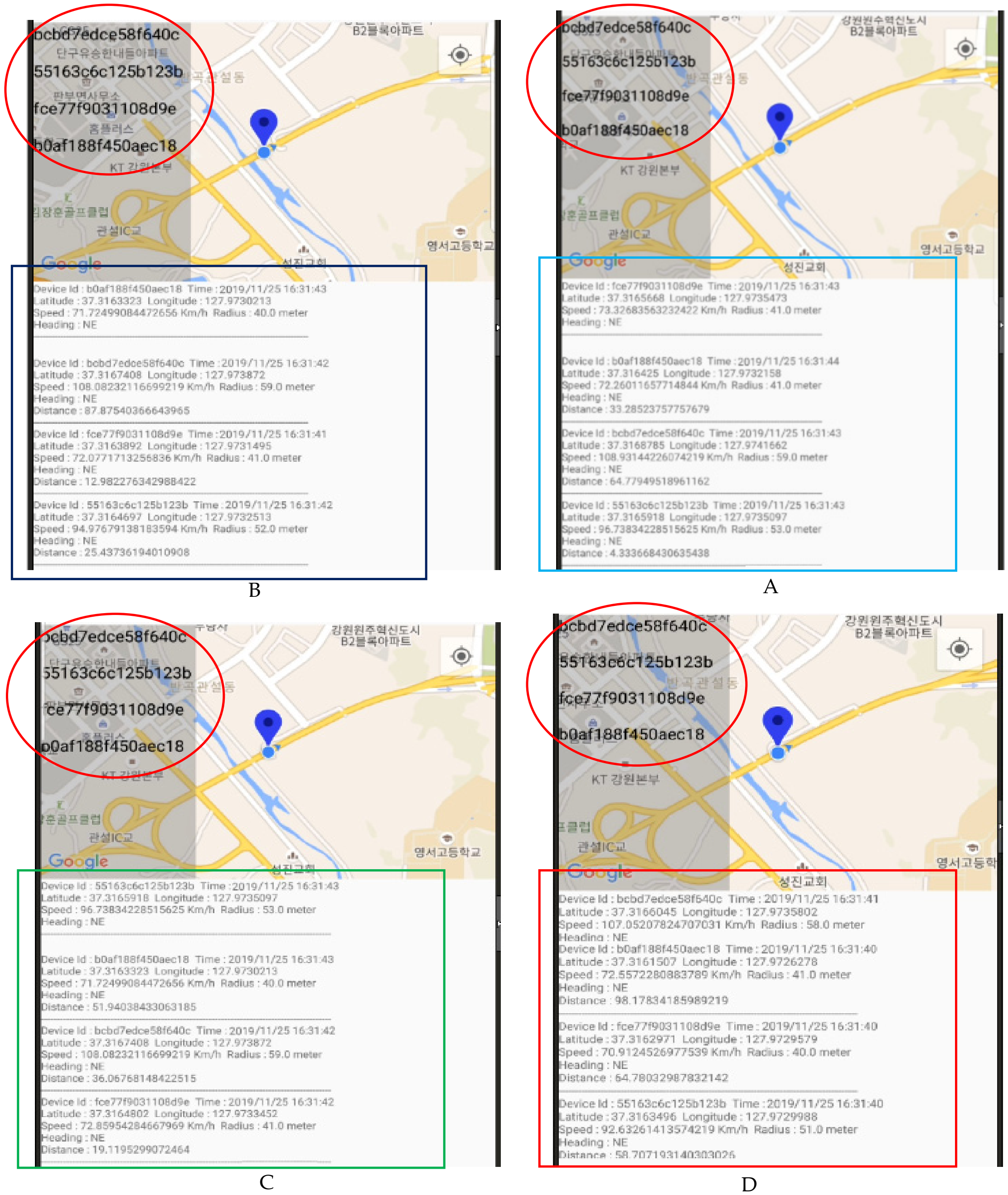


Figure 13. Images of screens when each vehicle overtakes the other.

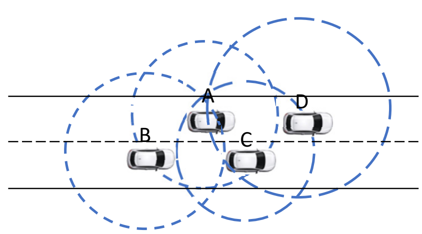


Figure 14. Conceptual illustration of the topological vehicle sequence shown in Figure 13.

4. Discussion

Although the connected car technology is applicable to future autonomous vehicles and smart cars, it does not apply to vehicles that are currently being produced [4,10]. If this technology is to be applicable to existing vehicles, it will require the attachment of additional devices such as an on-board unit (OBU). To prevent accidents, Advanced Driver Assistance Systems (ADAS*)* installed on existing vehicles are not optimum systems for the driver, and they provide neither the connected car technology nor self-driving [31]. Even if a vehicle is equipped with the Autonomous Emergency Braking (AEB) system, the vehicle will automatically apply the emergency brakes when other vehicles driving around the vehicle overtake and intervene. In this case, vehicles that immediately follow may cause a collision. Therefore, it is also important to understand the situation information of other vehicles that are currently driving around a vehicle. Hence, it is necessary to form a connected car subgroup.

Therefore, this paper proposed and experimented three algorithms that improve the performance of the CMVF system using smartphones and the connected car technology. The proposed algorithms distinguish the representative direction in which vehicles are driven and allow vehicles in the connected group to recognize each other's topological sequence. This is an important concept, and if the preceding vehicle meets with an accident, it can be prevented by notifying the following vehicle in advance that the preceding vehicle is dangerous. As vehicles traveling in the reverse direction do not need to recognize information of those moving in the forward direction, the problem of message congestion or contention to disseminate emergency messages may occur less frequently. The zone of relevance (ZOR) and a ring-based approach of vehicle-density-based emergency broadcast (VDEB) have been proposed to solve the dissemination problem of emergency messages while avoiding problems such as the broadcast storm or message contention [32,33]. However, these solutions are very theoretical and rely on several network simulation tools. In addition, studies on installing a sensor belt section on the road would require selecting the proper section range, and it is not a realistic solution, due to very expensive construction costs [33].

5. Conclusions

This paper presented a topological sequence recognition mechanism for forming a connected car-based subgroup and recognizing the geographical location and relative position according to the dynamic topology changes of the preceding or following vehicles for each vehicle in the subgroup. Further, this paper applied this mechanism to the CMVF system and verified its efficiency by driving on a real road. To prevent accidents, even autonomous vehicles or vehicles with advanced driving assistants can be rendered safe if information can be obtained on the situation of other vehicles in the vicinity. In addition, in the NLOS environment, traffic and road situation information from preceding vehicles is more important. In these cases, there are problems such as the broadcast storm or message congestion in information while disseminating messages.

The proposed topological sequence recognition mechanism as a solution can alleviate the problems of message dissemination as each vehicle knows the situation of other vehicles that are in front of and behind it. Furthermore, the proposed mechanism does not disseminate messages to vehicles that are being driven in the reverse direction, because vehicles are aware of the driving directions between one another. In particular, to prevent secondary accidents due to vehicle accidents that have occurred in the front, when the preceding vehicles deliver emergency messages, the proposed mechanism is very effective because the following vehicles are known, and the messages can only be disseminated to the following vehicles. Meanwhile, the CMVF client uses a smartphone, and therefore, even if it is not an autonomous vehicle or connected car, the connected car service can be provided using a smartphone of a driver who is driving a non-autonomous vehicle.

Even if connected car technology is not fully realized in previously manufactured vehicles, the proposed mechanism can be used by a driver's smartphone itself or applied to the current navigation system. In vehicles that will be manufactured in the future, it is necessary to incorporate the proposed mechanism in the Electronic Control Unit (ECU) or the trip computer of autonomous vehicles for safer autonomous driving.

Author Contributions: E.Y.H., G.H., M.L. designed the present study; Y.G.C., S.C. and B.J. reviewed the literature, and drafted the manuscript; E.Y.H., G.H. and M.L. performed the system workflow and implementation of the proposed algorithms; Y.G.C., S.C., R.Y.C.K. and B.J. critically revised the manuscript. All authors have read and agreed to the submitted version of the manuscript.

Funding: This study was supported by the 2020 Academic Research Support Program in Gangneung-Wonju National University and the Basic Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (NRF-2017R1D1A3B03034102). The present research has also been conducted by the Research Grant of Kwangwoon University in 2019.

Conflicts of Interest: The authors have no conflict of interest.

References

1. Castaño, F.; Strzelczak, S.; Villalonga, A.; Haber, R.E.; Kossakowska, J. Sensor Reliability in Cyber-Physical Systems Using Internet-of-Things Data: A Review and Case Study. *Remote Sens.* **2019**, *11*, doi:10.3390/rs11192252.
2. Greenough, J. *The CONNECTED CAR REPORT: Forecasts, Technologies, and Leading Manufacturers*; Business Insider Intelligence: New York, NY, USA, ,2016.
3. Andrew, M. *Automotive Industry Trends: IoT Connected Smart Cars & Vehicles*; Business Insider: New York, NY, USA, 2017.
4. Eom, Y.H.; Kim, I.H.; Yoo, H.M.; Cho, S.K.; Jeon, B.K. Design of the Emergency Messages Integration for Vehicle to Everything (V2X) Communications of Connected Cars. *International Journal of Engineering and Technology*. **2018**, *7*, 2–14.
5. European Telecommunications Standards Institute, *Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service*, European Telecommunications Standards Institute: Sophia Antipolis, France, 2013.
6. Tseng, Y.C.; Ni, S.Y.; Chen, Y.S.; Sheu, J.P. The broadcast storm problem in a mobile ad hoc network. *Wirel. Netw.* **2002**, *8*, 153–167.
7. Yu, S.; Cho, G. An effective message flooding method for vehicle safety communication. In *International Conference on Ubiquitous Intelligence and Computing*; Springer: Berlin/Heidelberg, Germany, 2006.
8. Gao, J.; Li, M.; Zhao, L.; Shen, X. Contention intensity based distributed coordination for V2V safety message broadcast. *IEEE Trans. Veh. Technol.* **2018**, *67*, 12288–12301.
9. Ghazi, M.U.; Khattak MA, K.; Shabir, B.; Malik, A.W.; Ramzan, M.S. Emergency Message Dissemination in Vehicular Networks: A Review. *IEEE Access* **2020**, *8*, 38606–38621.
10. Eom, Y.H.; Cho, S.K.; Kim, R.Y.C.; Jeon, B.K. Design and Implementation of a Speed-reactive Connected Mobile Virtual Fence System with Context-aware Computing. *J. Eng. Technol.* **2018**, *7*, 307–321.
11. Thakur, T.T.; Naik, A.; Vatari, S.; Gogate, M. Real time traffic management using Internet of Things, In Proceedings of the 2016 International Conference on Communication and Signal Processing (ICCSP), 2016; pp. 1950–1953.
12. Balakrishna, S.; Thirumaran, M. Semantic interoperable traffic management framework for IoT smart city applications. *EAI Endorsed Trans. Internet Things* **2018**, *4*, 155482.
13. Sumi, L.; Ranga, V. Intelligent traffic management system for prioritizing emergency vehicles in a smart city. *Int. J. Eng.* **2018**, *31*, 278–283.
14. Younes, M.B.; Boukerche, A. An efficient dynamic traffic light scheduling algorithm considering emergency vehicles for intelligent transportation systems. *Wirel. Netw.* **2017**, *24*, 2451–2463.
15. Tian, D.; Liu, C.; Duan, X.; Sheng, Z.; Ni, Q.; Chen, M.; Leung, V.C.M. A distributed position-based protocol for emergency messages broadcasting in vehicular ad hoc networks. *IEEE Internet Things J*. **2018**, *5*, 1218–1227.
16. Ucar, S.; Ergen, S.C.; Ozkasap, O. Multihop-cluster-based IEEE 802.11 p and LTE hybrid architecture for VANET safety message dissemination. *IEEE Trans. Veh. Technol.* **2015**, *65*, 2621–2636.
17. Khabazian, M.; Aissa, S.; Mehmet-Ali, M. Performance modeling of message dissemination in vehicular ad hoc networks with priority. *IEEE J. Sel. Areas Commun*. **2011**, *29*, 61–71.
18. Suthaputchakun, C.; Dianati, M.; Sun, Z. Trinary partitioned BlackBurst-Based broadcast protocol for time-critical emergency message dissemination in VANETs. *IEEE Trans. Veh. Technol.* **2014**, *63*, 2926–2940.
19. Shabir, B.; Khan, M.A.; Rahman, A.U.; Malik, A.W.; Wahid, A. Congestion avoidance in vehicular networks: A contemporary survey. *IEEE Access* **2019**, *7*, 173196–173215.

20. Ullah, A.; Yaqoob, S.; Imran, M.; Ning, H. Emergency message dissemination schemes based on congestion avoidance in VANET and vehicular FoG computing. *IEEE Access* **2019**, *7*, 1570–1585.
21. Chang, B.J.; Liang, Y.H.; Huang, Y.D. Efficient emergency forwarding to prevent message broadcasting storm in mobile society via Vehicle to-X communications for 5G LTE-V. In Proceedings of the 2016 International Computer Symposium (ICS), Chiayi, Taiwan, 15–17 December 2016; pp. 479–484.
22. Choi, Y.K.; Cho, S.K.; Park, S.K.; Eom, Y.H.; Kim, I.H.; Jeon, B.K. An extended three-dimensional Geofence platform with rule-based context-awareness service for the internet of things. *J. Eng. Technol.* **2018**, *6*, 318–328.
23. Golestan, K.; Soua, R.; Karray, F.; Kamel, M.S. Situation awareness within the context of connected cars: A comprehensive review and recent trends. *Inf. Fusion* **2016**, *29*, 68–83.
24. Kim, I.H.; Yoo, H.M.; Eom, Y.H.; Cho, S.K.; Jeon, B.K. A Mutual Awareness Mechanism of Inter-MVFs(Mobile Virtual Fences) to Support Connected Car Service. *Int. J. Eng. Technol.* **2018**, *7*, 106–108.
25. Kim, I.H.; Yoo, H.M.; Eom, Y.H.; Cho, S.K.; Jeon, B.K. An Integrated Communication Message Framework of Inter-Vehicles for Connected Vehicles using Mobile Virtual Fence(MVF*) Int. J. Eng. Technol.* **2018**, *7*, 102–105.
26. NHTSA. *Federal Motor Vehicle Safety Standards*; V2V Communications; NHTSA: Washington, DC, USA, 2017.
27. SAE J2735. *Dedicated Short Range Communications (DSRC) Message Set Dictionary*; SAE International: Warrendale, PA, USA, 2016.
28. European Telecommunications Standards Institute. *Specifications of Decentralized Environmental Notification Basic Service*; European Telecommunications Standards Institute: Sophia Antipolis, France, 2014.
29. Bergamini, E.; Ligorio, G.; Summa, A.; Vannozzi, G.; Cappozzo, A.; Sabatini, A.M. Estimating Orientation using Magnetic and Inertial Sensors and Different Sensor Fusion Approaches: Accuracy Assessment in Manual and Locomotion Tasks. *Sensors* **2014**, *14*, 18625–18649.
30. Hwang, J.M.; Kim, J.H. Development of the Calibration Algorithm of3Axis Vector Sensor using Ellipsoid. *J. Korean Soc. Precis. Eng.* **2015**, *32*, 643–651.
31. *Choi, S.H.; Thalmayr, F.; Wee, D.; Weig, F. Advanced Driver-Assistance Systems: Challenges and Opportunities;* McKinsey & Company: New York, NY, USA, 2016.
32. Tseng, Y.T.; Jan, R.H.; Chen, C.; Wang, C.F.; Li, H.H. A Vehicle-density-based Forwarding Scheme for Emergency Message Broadcasts in VANETs, In Proceedings of The 7th IEEE International Conference on Mobile Ad-hoc and Sensor Systems (IEEE MASS 2010), San Francisco, CA, USA, 8–12 November 2010; pp. 703–708.
33. Abuelela, M.; Olariu, S.; Weigle, M.C. NOTICE: An Architecture for the Notification of Traffic Incidents. *IEEE Intell. Transp. Syst. Mag.* 2012, *4*, 6–16.