

Received April 21, 2020, accepted April 29, 2020, date of publication May 6, 2020, date of current version May 18, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2992545

# An Emergence Alert Broadcast Based on Cluster Diversity for Autonomous Vehicles in Indoor Environments

**SEKCHIN CHANG** 

Department of Electrical and Computer Engineering, University of Seoul, Seoul 02504, South Korea

e-mail: schang213@uos.ac.kr

This work was supported by the Research Program through the National Research Foundation of Korea (NRF) under Grant 2017R1A2B4005105.


**ABSTRACT** This paper addresses an emergency alert broadcast for autonomous vehicles in indoor environments. For a rapid alert broadcast, a novel cluster diversity is proposed. Using the cluster diversity, the alert broadcast can significantly reduce the number of rebroadcasts. This leads to the rapid delivery of emergency alerts. The cluster diversity consists of clustering and diversity combining. For the clustering, the cluster diversity technique utilizes the location information of autonomous vehicles. Using the location information, a cluster head is selected in each cluster. The cluster head rebroadcasts the emergency alert to the autonomous vehicles. Therefore, the clustering can lessen the number of rebroadcasts. In order to further reduce the number of rebroadcasts, a diversity combining technique is proposed in this paper. The diversity approach is based on the clustering. For the diversity, the emergency alert packet is repeated in the transmitted OFDM block. For each cluster, the emergency alert packet can orthogonally be allocated to the corresponding frequency sub-band in the OFDM block. In the received OFDM block, the autonomous vehicle utilizes the emergency alert packet with the maximum power in order to achieve a diversity. The experimental results exhibit that the proposed cluster diversity can considerably reduce the number of rebroadcasts in indoor environments. The results also show that the presented approach substantially outperforms the conventional technique in terms of the number of outage vehicles in the cases of rebroadcasts under indoor environments.

**INDEX TERMS** Emergency alert, broadcast, clustering, diversity, vehicle, OFDM.

## I. INTRODUCTION

Recently, lots of attention has been paid to smart cities, which offer various automation strategies based on high technologies for better life qualities [1]. Especially, autonomous vehicle systems are considered essential elements in the automation strategies [2]. In addition, a smart building is one of the fundamental components in the smart cities [3]. In modern cities including the smart cities, reliable emergency alert systems are also required in order to effectively sustain the life qualities even in severe disaster situations [4]. Nowadays, the emergency alert systems heavily rely on advanced telecommunication systems including 5G cellular systems, mobile broadcast systems, and internet-of-things (IoT) [5]–[7]. Especially, the 5G cellular systems offer an alert broadcast mechanism, which is called

cellular broadcast service (CBS) [8]. In addition, an advanced emergency alert (AEA) broadcast is defined in the standard of advanced television systems committee (ATSC) 3.0 [9], which is one of the latest standards for mobile broadcast systems. The IoT technologies also enable an emergency alert broadcast even when the network infrastructures such as 5G or broadcast systems are disabled due to natural or social disasters [10]. However, these methods [8]–[10] are used for emergency alert delivery in outdoor environments. In smart cities, indoor areas including smart buildings may often be under serious emergency situations such as collapse or fire. Moreover, the emergency alert technologies [8]–[10] rely on a carousel mechanism [11] for rebroadcasts in order to diminish a probability that some recipients fail in decoding the emergency alert message correctly. The carousel mechanism may cause a high latency especially when wireless channels experience poor conditions. Note that the poor channel conditions may frequently occur in indoor

The associate editor coordinating the review of this manuscript and approving it for publication was Fang Yang .

environments [12]. Furthermore, vehicles need to be evacuated quickly in the case of severe emergency including collapse or fire in buildings or undergrounds. Therefore, the conventional carousel technique is not suitable for the emergency alert broadcast in indoor environments.

This paper addresses a novel emergency alert broadcast approach for autonomous vehicles in indoor environments such as smart buildings. The autonomous vehicles can locate their positions and make vehicular communications [13]. Especially for autonomous vehicle systems and vehicular communications, specific research works can be found in [14]–[18]. An energy-aware dynamic resource allocation scheme was proposed for internet of vehicles [14]. A learning algorithm was presented for intelligent resource allocation in vehicular networks [15]. Multicasting and congestion control modules were investigated for intelligent vehicle terminals in internet of vehicles [16]. A machine learning approach was utilized for vehicular social networks (VSNs) in 5G networks [17]. Security and energy issues were investigated in wireless sensor networks [18]. In this paper, the novel broadcast method utilizes a proposed cluster diversity in the cases of rebroadcasts. Using the cluster diversity, the alert broadcast considerably lessens the number of rebroadcasts. This can lead to the rapid delivery of emergency alerts to all the autonomous vehicles in indoor environments. The presented cluster diversity is composed of clustering and diversity combining. In order to make the effective clustering, the cluster diversity technique exploits the location information of autonomous vehicles. Whenever a cluster is determined, a cluster head is selected in the cluster. The cluster head delivers the emergency alert to the autonomous vehicles in the cases of rebroadcasts. Using the cluster head, the distance between transmitter and receiver is shorten in the cases of rebroadcasts. Therefore, the clustering contributes to the significant reduction of the number of rebroadcasts. In order to further reduce the number of rebroadcasts, a diversity combining approach is proposed in this paper. The presented diversity technique is based on the clustering. In order to achieve a diversity, the emergency alert packet is repeated in the transmitted data block. The orthogonal frequency division multiplexing (OFDM) block [19] is used as the data block. For each cluster, the alert packet can orthogonally be allocated to the corresponding frequency sub-band in the OFDM block. This can also avoid the interferences from the other clusters. In the received OFDM block, the autonomous vehicle utilizes the emergency alert packet with the maximum power. Even in the cases of cluster heads with same distances, this diversity approach can be reduced to the selection combining technique [20].

Experimental evaluation reveals the validity of the proposed emergency alert broadcast approach. The experimental results show that the proposed cluster diversity can substantially reduce the number of rebroadcasts in the indoor areas. The results also exhibit that the presented method is much superior to the conventional carousel technique [11] in terms

of the number of outage vehicles in the cases of rebroadcasts in the indoor environments.

## II. SYSTEM MODEL

As a system model, consider autonomous vehicles inside a smart building. The smart building is generally a multi-layered building. In the smart building, each layer usually employs the separate transmitter for emergency alert broadcast. Therefore, the proposed strategy is applicable to each single layer in the multi-layered smart building in this system model. If the building detects an emergency, it broadcasts the alert message to the vehicles using a broadcast protocol. In the systems model, it is assumed that the autonomous vehicle can make vehicular localization and vehicular communications, which include vehicle-to-building communications. In the system model, it is assumed that the smart building is capable of identifying the cluster heads. Using the vehicle-to-building communications, the vehicles can transmit location and outage information to the smart building for the cluster head identification.

Table 1 summarizes the properties of the system model for the proposed emergency alert broadcast. Table 1 exhibits initial cluster size, broadcast (transmitter) source, and vehicle node distribution. The cluster size is initially determined in the emergency alert broadcast. If the size of the indoor area is  $200\text{m} \times 200\text{m}$ , the initial cluster size is  $100\text{m} \times 100\text{m}$  or  $200\text{m} \times 100\text{m}$  depending on the location of the originator (original transmitter) for broadcast. Note that each cluster size depends on the distribution of outage vehicles in the rebroadcast cases. For the transmission of emergency alert to the vehicles, the broadcast (transmitter) source follows the WAVE protocol [22], which is described in section II-A. In order to avoid any bias in the presented approach, the random distribution of the vehicle nodes follows the uniform distribution in the indoor area.

**TABLE 1. The properties of the system model for emergency alert broadcast.**

System Model	Property
Smart building layer	Multi-layer
Place of each transmitter for broadcast	Each Single Layer in the multi-layered smart building
Initial Cluster size <sup>1</sup>	100m x 100 m / 200m x 100m
Broadcast (transmitter) source	WAVE protocol [22]
Distribution of vehicle nodes	Uniform distribution

<sup>1</sup> It is assumed that the indoor area size is  $200\text{m} \times 200\text{m}$ .

### A. EMERGENCY ALERT BROADCAST IN INDOOR ENVIRONMENTS

The 5G cellular systems rely on the CBS mechanism [8] in order to broadcast the emergency alert in outdoor environments. In 4G/5G cellular systems, the base station uses the system information block (SIB) in order to broadcast the required information to all the mobile stations in the

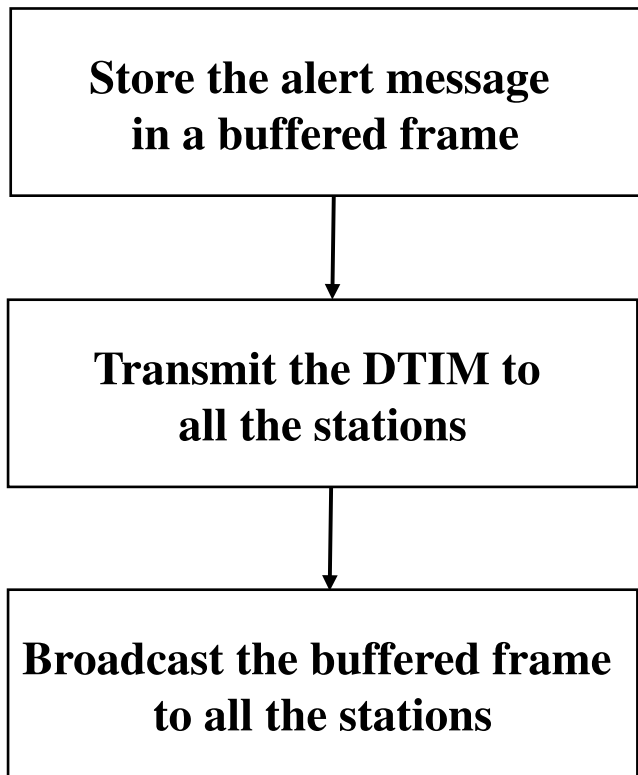


FIGURE 1. The procedure of the emergency alert broadcast using the beacon frame in the IEEE 802.11 transmitter.

cell [21]. Especially, the 5G CBS uses SIB 7 or SIB 8 in order to broadcast the emergency alerts in the cell [21]. Since autonomous vehicles usually adopts the IEEE 802.11p WAVE [22] for vehicular communications, the emergency alert broadcast can rely on the IEEE 802.11 protocol in indoor environments. Note that the WAVE [22] uses the OFDM block for transmission. The 802.11 protocol uses a beacon frame in order to broadcast a buffered information to all the stations in the indoor area [23], which is similar to the cases of 4G/5G cellular systems. Figure 1 illustrates the procedure of the emergency alert broadcast using the beacon frame [23] in the IEEE 802.11 transmitter.

As shown in Figure 1, the 802.11 transmitter store the alert message in a buffered frame. Then, the transmitter sends the delivery traffic indication map (DTIM) [23] in order to inform all the stations that it has a buffered frame to be broadcast. Then, the transmitter broadcasts the buffered frame to all the stations.

**B. VEHICULAR LOCALIZATION**

Since indoor channels usually render poor conditions, it is assumed that the vehicular localization is based on inertial devices in this system model. Therefore, the autonomous vehicles can estimate their locations using the inertial measure unit (IMU). Figure 2 illustrates the vehicular localization based on the IMU [24], [25]. As shown in Figure 2, the IMU generates the vehicular attitude (roll/pitch/yaw). Then, the Kalman filtering [26] estimates the vehicular

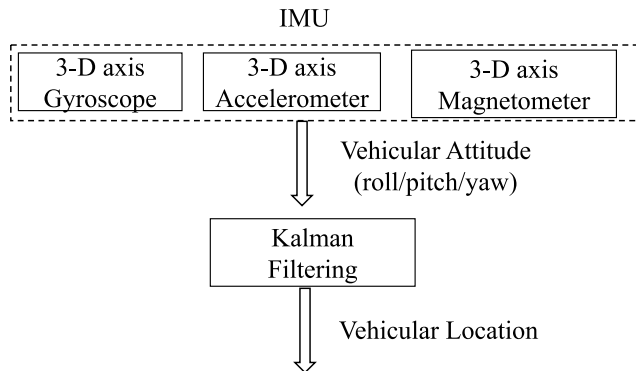


FIGURE 2. The vehicular localization based on the IMU.

locations using the vehicular attitude. This enables a vehicular localization even in indoor environments.

**III. THE EMERGENCY ALERT BROADCAST BASED ON CLUSTER DIVERSITY**

For a rapid broadcast of emergency alerts to autonomous vehicles, we have to minimize the number of rebroadcasts. Assume a random variable  $\eta_i$ , which denotes the number of total broadcasts for successful transmission of an emergency alert packet to  $i$ th vehicle. Thus, the expected value of  $\eta_i$  is expressed as follows:

$$E[\eta_i] = \sum_{k=0}^{\infty} (k + 1)Pr_i(K = k), \tag{1}$$

where  $K$  denotes the number of attempts required to successfully transmit the emergency alert packet. In (1),  $Pr_i(K = k)$  defines the probability that the first  $k$  attempts will fail and the  $(k + 1)$ th attempt will succeed. This indicates that the last  $(k + 1)$ th attempt is the only success transmission out of  $k + 1$  independent trials (transmissions). If the probability of the transmission failure is  $p_e$  each attempt, the probability of the transmission success is  $1 - p_e$ . Therefore, the random variable  $K$  follows a geometric distribution in (1) [27]. Since  $K$  follows a geometric distribution in (1),  $Pr_i(K = k)$  can be expressed as follows:

$$Pr_i(K = k) = p_{e,i}^k (1 - p_{e,i}), \tag{2}$$

where  $p_{e,i}$  denotes the probability of an erroneous transmission of the emergency alert packet to the  $i$ th vehicle. After the substitution of (2) into (1),  $E[\eta_i]$  of (1) can also be expressed as follows:

$$E[\eta_i] = \frac{1}{1 - p_{e,i}}. \tag{3}$$

Note that the emergency alert packet is independently broadcast to all the vehicles. If a random variable  $\eta$  is defined as the number of total broadcasts for successful transmission of an emergency alert packet to  $M$  vehicles, the expected value of  $\eta$  can be expressed as follows:

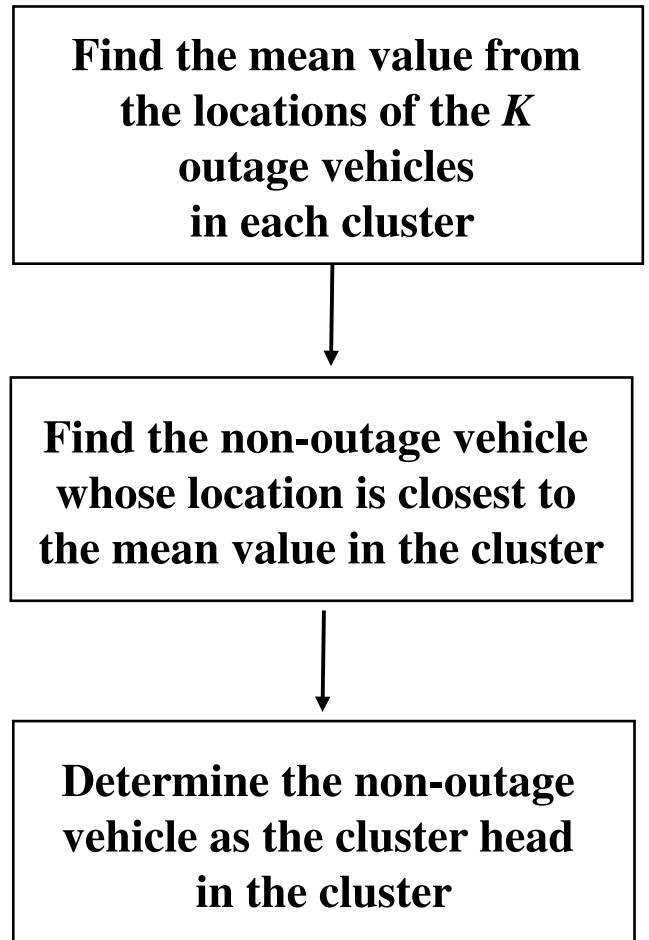
$$E[\eta] = \frac{E[\eta_1]E[\eta_2] \cdots E[\eta_M]}{1 - (1 - p_{e,1})(1 - p_{e,2}) \cdots (1 - p_{e,M})}. \tag{4}$$

In order to diminish the number of rebroadcasts, we need to reduce the value of  $E[\eta]$ . In (4), we have to decrease  $p_{e,i}$  in order to reduce  $E[\eta]$ . In order to lessen  $p_{e,i}$ , the broadcast scheme exploits the proposed cluster diversity in this paper. Using the cluster diversity, the broadcast approach can significantly reduce the number of rebroadcasts. This leads to the rapid delivery of emergency alerts to autonomous vehicles in indoor environments. The cluster diversity consists of clustering and diversity combining.

**A. THE CLUSTERING FOR EMERGENCY ALERT BROADCAST**

The proposed clustering algorithm is divided into the center case and the edge case.

Figure 3 illustrates the center case in clustering. As shown in Figure 3, the original transmitter (originator) is located around the center in the indoor area. When an emergency occurs, the originator broadcasts the emergency alert to all the vehicles as the 1st broadcast in the area. Figure 3 also shows that the area consists of 4 clusters. Figure 4 illustrates that each cluster includes the outage and the non-outage vehicles after the originator broadcasts the emergency alert (the 1st broadcast) in the center case. After the 1st broadcast, a cluster head is identified among the non-outage vehicles in each cluster. In other words, the 4 cluster heads are found in the indoor area as shown in Figure 4. Figure 5 shows the procedure of the cluster-head identification. The procedure is based

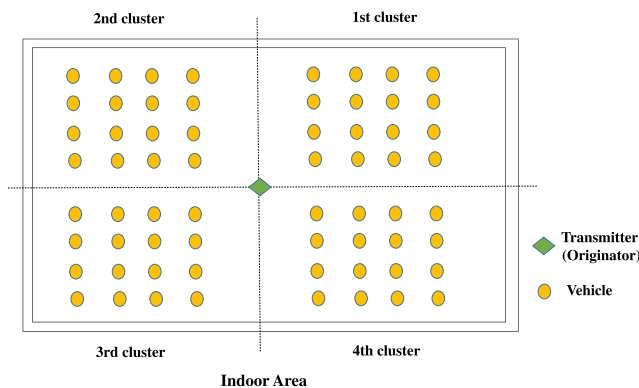


**FIGURE 5.** The procedure of the cluster-head identification.

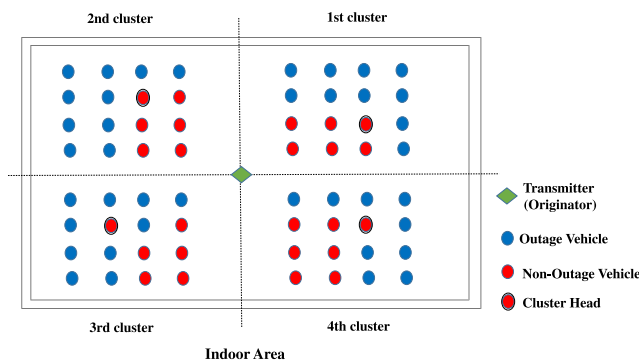
on the head searching method for the  $K$  nearest neighbor (KNN) clustering [28]. As depicted in Figure 5, the identification algorithm finds the mean value from the locations of the  $K$  outage vehicles in each cluster. Then, the algorithm finds the non-outage vehicle whose location is closest to the mean value in the cluster. Finally, the non-outage vehicle is determined as the cluster head. As indicated in Figure 5, the identification method utilizes the location information of the vehicles. Note that the autonomous vehicles can produce their location information as stated in section II-B. Since the cluster head holds the valid emergency alert from the originator, it can rebroadcast the same alert to the outage vehicles in the cluster.

Figure 6 illustrates the outage states of the vehicles after the 2nd broadcast in the center case. Unlike the 1st broadcast case, the outage vehicles receive the emergence alert from the cluster heads in the 2nd broadcast case. Therefore, the cluster head is nearer to the outage vehicles in the cluster than the originator. The relation between transmitted signal power and received signal power is well described by the simplified path-loss model [29]. The model is expressed as follows:

$$P_r = P_t K \left( \frac{d_0}{d} \right)^\gamma, \tag{5}$$



**FIGURE 3.** The center case in the clustering.



**FIGURE 4.** The outage and the non-outage vehicles after the 1st broadcast in the center case.

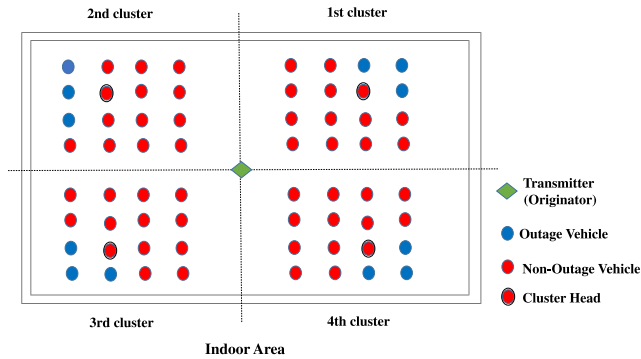


FIGURE 6. The outage states of the vehicles after the 2nd broadcast in the center case.

where  $P_t$  and  $P_r$  are the transmitted signal power and the received signal power, respectively. In (5),  $K$ ,  $d_0$ ,  $\gamma$ , and  $d$  denote a unit-less constant, a reference distance, a path-loss component, and a distance between transmitter and receiver, respectively. From (5), it is revealed that shorter distance ( $d$ ) guarantees larger received power ( $P_r$ ). Since  $1 - p_{e,i}$  is proportional to  $P_r$  in (4), where  $i = 1, 2, \dots, M$ , it is more likely that the outage vehicles successfully receive the alert in the rebroadcast case. Therefore, we can expect smaller  $E[\eta]$  of (4) in the 2nd broadcast. If there are still outage vehicles in any cluster after the 2nd broadcast, a new cluster head is identified among the non-outage vehicles in the cluster, which is shown in Figure 6. The new cluster heads further reduce the distance ( $d$ ) in (5). For the identification, the procedure of Figure 5 is utilized. Then, the new cluster heads initiate the 3rd broadcast to the outage vehicles. From the comparison of Figure 4 and Figure 6, it is known that the new cluster heads are nearer to the outage vehicles than the old cluster heads. Therefore, it is more likely that the number of non-outage vehicles noticeably increases in the 3rd broadcast. The cluster head identification and the rebroadcast continue until all the vehicles correctly decode the emergency alert.

Figure 7 illustrates the edge case in clustering. As shown in Figure 7, the originator is located around the edge in the indoor area. When an emergency occurs, the originator (around the edge) broadcasts the emergency alert to all the vehicles as the 1st broadcast in the area. Unlike the center case of Figure 3, there are only 2 clusters in the edge case of Figure 7. Figure 8 illustrates that each cluster includes the outage and the non-outage vehicles after the originator broadcasts the emergency alert (the 1st broadcast) in the edge case. As shown in Figure 8, most non-outage vehicles concentrate around the edge originator. Therefore, after the 1st broadcast, the indoor area must be partitioned into 2 clusters (upper and lower clusters). Otherwise, some clusters may not include any non-outage vehicle. In this case, we cannot find the cluster heads for the clusters. Like the case of Figure 4, a cluster head needs to be identified among the non-outage vehicles in each cluster (upper or lower cluster). The identification also relies on the procedure of Figure 5. In this case, the 2 cluster heads are identified in the indoor area, which is shown in Figure 8.

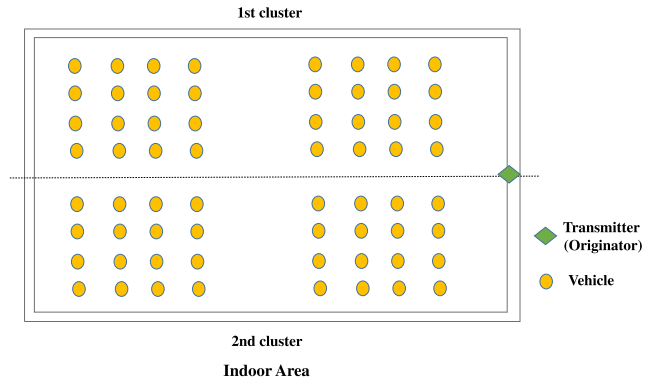


FIGURE 7. The edge case in the clustering.

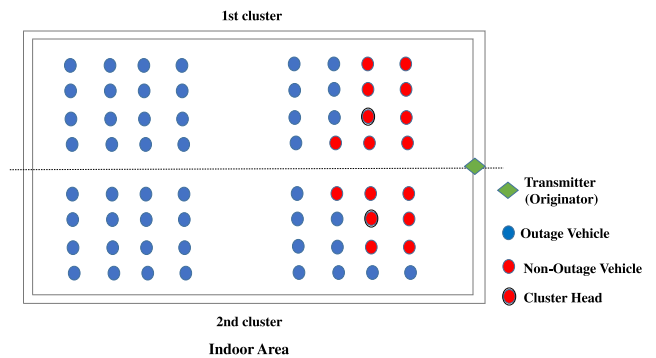


FIGURE 8. The outage and the non-outage vehicles after the 1st broadcast in the edge case.

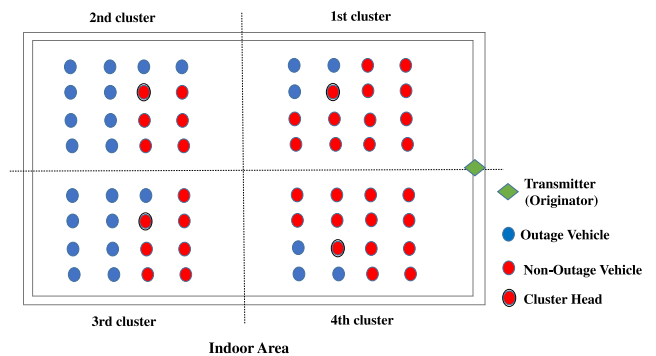


FIGURE 9. The outage states of the vehicles after the 2nd broadcast in the edge case.

Figure 9 illustrates the outage states of the vehicles after the 2nd broadcast in the edge case. Unlike the 1st broadcast case, the outage vehicles receive the emergence alert from the selected cluster head. Since the cluster head is nearer to the outage vehicles in the cluster than the edge originator, it is also more likely that the outage vehicles successfully decode the alert in the rebroadcast case. If there are still outage vehicles after the 2nd broadcast, some new cluster heads need to be identified among the non-outage vehicles. In this case, the non-outage vehicles are more evenly distributed on the entire area, which is shown in Figure 9. Therefore, the 4 clusters need to be selected for more reliable rebroadcasts. For the identification of the new 4 cluster heads, the procedure of Figure 5 is also utilized. Then, the new 4 cluster heads



initiate the 3rd broadcast to the outage vehicles. From the comparison of Figure 8 and Figure 9, it is also revealed that the new 4 cluster heads are much nearer to the outage vehicles than the old 2 cluster heads. Therefore, it is also more likely that the number of non-outage vehicles significantly increases in the 3rd broadcast. The 4 cluster-head identification and the rebroadcast continue until all the vehicles correctly decode the emergency alert.

---

**Algorithm 1** Proposed Clustering Algorithm for the Center Case

---

```

Receive_Alert(all, center)
    // All vehicles try to receive the alert
    // packet from the center originator.
while there is an outage vehicle do
    for  $i=1$  to 4 do
        [out, non]  $\leftarrow$  Find_Out_Non( $i$ )
            // Find outage and non-outage
            // vehicles in the  $i$ th cluster.
        head  $\leftarrow$  Find_Head( $i$ , out, non)
            // Find the cluster head among
            // the non-outage vehicles in
            // the  $i$ th cluster.
        Receive_Alert_CD( $i$ , out, head)
            // The outage vehicles try to
            // receive the alert packet from
            // the head in the  $i$ th cluster using
            // the cluster diversity.

```

---

The proposed clustering algorithms for the center and the edge cases are given in Algorithm I and Algorithm II, respectively.

We describe the relationship between the system model (Table 1) and the clustering policy (Figure 3 to Figure 9) as follows:

- In Figure 3 to Figure 9, the clustering approach is suitable for each single layer in multi-layered smart buildings (Table 1).
- In Figure 3, the initial cluster size is  $100\text{m} \times 100\text{m}$  if the indoor area size is  $200\text{m} \times 200\text{m}$  (Table 1).
- In Figure 4 and Figure 6, the cluster size varies according to the distribution of outage vehicles.
- In Figure 7, the initial cluster size is  $200\text{m} \times 100\text{m}$  if the indoor area size is  $200\text{m} \times 200\text{m}$  (Table 1).
- In Figure 8 and Figure 9, the cluster size varies according to the distribution of outage vehicles.
- In Figure 3 to Figure 9, the broadcast source (originator/transmitter) follows the WAVE protocol (Table 1).
- In Figure 3 to Figure 9, the vehicle nodes are uniformly distributed (Table 1).

## B. THE DIVERSITY COMBINING BASED ON THE CLUSTERING

The section III-A states that the proposed clustering can considerably reduce the distance ( $d$ ) of (5) in the rebroadcast

---

**Algorithm 2** Proposed Clustering Algorithm for the Edge Case

---

```

Receive_Alert(all, edge) // All vehicles try to receive the alert
    // packet from the edge originator.
for  $i=1$  to 2 do //1st broadcast case
    [out, non]  $\leftarrow$  Find_Out_Non_E( $i$ )
        // Find outage and non-outage
        // vehicles in the  $i$ th cluster.
    head  $\leftarrow$  Find_Head_E( $i$ , out, non)
        // Find the cluster head among
        // the non-outage vehicles in
        // the  $i$ th cluster.
    Receive_Alert_CD_E( $i$ , out, head)
        // The outage vehicles try to
        // receive the alert packet from
        // the head in the  $i$ th cluster
        // using the cluster diversity.
while there is an outage vehicle do //After the 2nd broadcast
    for  $i=1$  to 4 do
        [out, non]  $\leftarrow$  Find_Out_Non( $i$ )
            // Find outage and non-outage
            // vehicles in the  $i$ th cluster.
        head  $\leftarrow$  Find_Head( $i$ , out, non)
            // Find the cluster head among
            // the non-outage vehicles in
            // the  $i$ th cluster.
        Receive_Alert_CD( $i$ , out, head)
            // The outage vehicles try to
            // receive the alert packet from
            // the head in the  $i$ th cluster
            // using the cluster diversity.

```

---

cases. In turn, this significantly reduces the number of rebroadcasts. In order to further decrease  $p_{e,i}$  in (4), where  $i = 1, 2, \dots, M$ , a diversity combining approach is proposed, which is based on the clustering.

In order to avoid the interferences from the other clusters in the rebroadcast, each cluster head follows an allocation scheme for transmission of the emergency alert packet. Figure 10 illustrates the allocation of the emergency alert packet for each cluster head. Like the IEEE 802.11p WAVE, the cluster heads rely on an OFDM technique for transmission. As shown in Figure 10, each cluster head allocates the emergency alert packet to the specified subcarrier sub-band in the OFDM block. Since there is no any overlap among the allocated packets in Figure 10, the cluster heads can rebroadcast the packets without any interference. If the  $i$ th cluster head generates one OFDM block including the emergency alert packet, the information symbol at the  $k$ th subcarrier in the OFDM block is denoted as  $X_i[k]$ . In  $X_i[k]$ ,  $i = 1, 2, \dots, L$ , and  $k = 1, 2, \dots, N$ , where  $L$  and  $N$  denote the numbers of cluster heads and subcarriers, respectively. Using the OFDM block, the  $i$ th cluster head produces the OFDM symbol

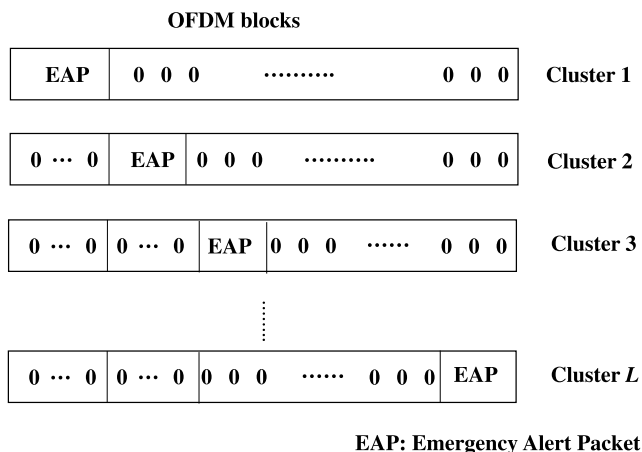


FIGURE 10. The allocation of emergency alert packet for each cluster head.

as follows:

$$x_i[n] = \text{IFFT}\{X_i[k]\}, \tag{6}$$

where  $n = 1, 2, \dots, N$ . In (6),  $\text{IFFT}\{\}$  denotes the operator of inverse fast Fourier transform (IFFT). After adding the cyclic prefix [22] to the OFDM symbol, the  $i$ th cluster head transmits the OFDM symbol with the cyclic prefix, which is denoted as  $\tilde{x}_i[n]$ . In each cluster, the outage vehicles receive the combined signal from all the cluster heads as follows:

$$\tilde{y}[n] = \sum_{i=1}^L h_i[n] * \tilde{x}_i[n] + z[n], \tag{7}$$

where  $*$  denotes the linear convolution operator. In (7),  $h_i[n]$  and  $z[n]$  represent the channel parameter between the  $i$ th cluster head and the outage vehicle, and the additive white Gaussian noise (AWGN), respectively. After removing the cyclic prefix from  $\tilde{y}[n]$ , the outage vehicles perform the following operation:

$$Y[k] = \text{FFT}\{y[n]\}, \tag{8}$$

where  $y[n]$  is the received signal without the cyclic prefix. In (8),  $\text{FFT}\{\}$  denotes the operator of fast Fourier transform (FFT). Then, the outage vehicles calculate the power ( $r_i$ ) of the received signal from the  $i$ th cluster as follows:

$$r_i = \frac{1}{J} \sum_{k=0}^{J-1} |Y[k + J \cdot (i - 1)]|^2, \tag{9}$$

where  $J$  denotes the length of the emergency alert packet, which is embedded in the OFDM block. Using the received signal power ( $r_i$ ), the outage vehicle estimates the allocation index of the emergency alert packet as follows:

$$\hat{i} = \arg \max_i [r_1 \ r_2 \ \dots \ r_i \ \dots \ r_L]. \tag{10}$$

Using the estimated index of (10), the outage vehicles extract the emergency alert packet from the OFDM block as follows:

$$\hat{Y}[k] = \begin{cases} Y[k], & J \cdot (\hat{i} - 1) \leq k < J \cdot \hat{i} \\ 0, & \text{else.} \end{cases} \tag{11}$$

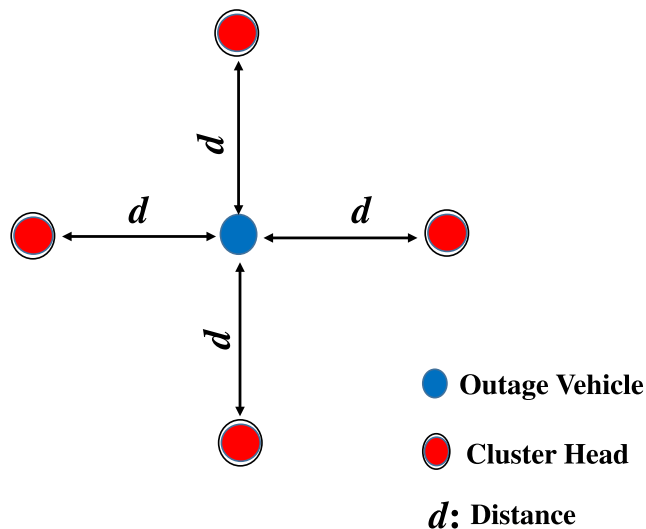


FIGURE 11. The scenario of the case 1.

Finally, the outage vehicles decode the extracted packet of (11).

As indicated in (9) to (11), the outage vehicles extract the emergency alert packet with the largest signal power. According to the path-loss model of (5), this indicates the outage vehicles utilize the alert packet from the cluster head, which belongs to the same cluster. Therefore, this presented method guarantees that the outage vehicles can use the emergency packet from the corresponding cluster head without any interference. Since the vehicles select the packet with maximum power from the repeated emergency alert packets, this proposed approach effectively exploits the selection combining technique [20], which is also verified in the section IV.

#### IV. EXPERIMENTAL EVALUATION

The experimental evaluation exhibits the effectiveness of the proposed cluster diversity approach for emergency alert broadcast in indoor environments.

Table 2 summarizes the 3 cases for this evaluation. The case 1 indicates the scenario that one outage vehicle receives the alert packet form the 4 cluster heads with the same distances. Figure 11 illustrates the scenario of the case 1. The cases 2 and 3 represent the scenarios that the originator is located at the center and the edge, respectively.

TABLE 2. The 3 cases for the evaluation.

Case	Scenario
Case 1	4 cluster heads with same distance
Case 2	Originator located at the center
Case 3	Originator located at the edge

Table 3 summarizes the experimental parameters for all the cases. The number of subcarriers in one OFDM block is 64, which is same as that of IEEE 802.11p WAVE. The number of subcarriers for one alert packet is 16. Therefore, the same

TABLE 3. The experimental parameters for the all the case.

Parameter	Value/Property
Number of subcarriers in one OFDM block	64
Number of subcarriers for packet	16
Fading channel	Exponential channel
Number of paths in the fading channel	10
Modulation	BPSK

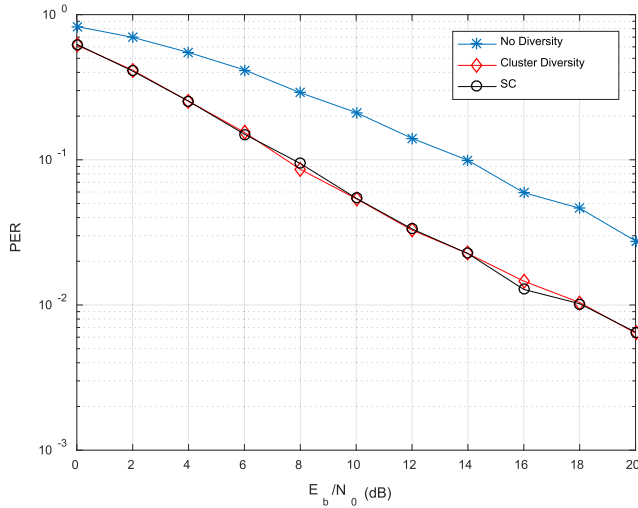


FIGURE 12. The comparison of the PER performance in the case 1.

packet can be repeated up to 4 times in one OFDM block. In this evaluation, the exponential channel [30] is adopted as the fading channel. For indoor environments, the number of channel paths is set to 10. As data modulation, BPSK is used in the evaluation.

Figure 12 exhibits a comparison of the packet error rate (PER) performance in the case 1. As shown in Figure 12, the proposed cluster diversity considerably enhances the PER performance even in the case of same distance. Figure 12 reveals that the cluster diversity achieves the gain of about 6 dB over the case of no diversity at the minimum sensitivity level (PER of 10%) [23]. Figure 12 also shows that the PER performance of the cluster diversity is comparable to that of the selection combining (SC) technique [20]. This confirms that the presented cluster diversity effectively exploits the diversity of the SC approach.

Table 4 includes the experimental parameters for case 2 and case 3. The cases 2 and 3 use 100 vehicles for this broadcast evaluation. In this evaluation, the total transmit power is 1 mW, which confirms a low-power transmission. The originator is located at the coordinates of (0,0) and (100,0) in the case 2 and the case 3, respectively.

TABLE 4. The experimental parameters for case 2 and case 3.

Parameter	Value
Number of vehicles	100
Total transmit power	1 mW
Coordinate of the center originator	(0,0)
Coordinate of the edge originator	(100,0)

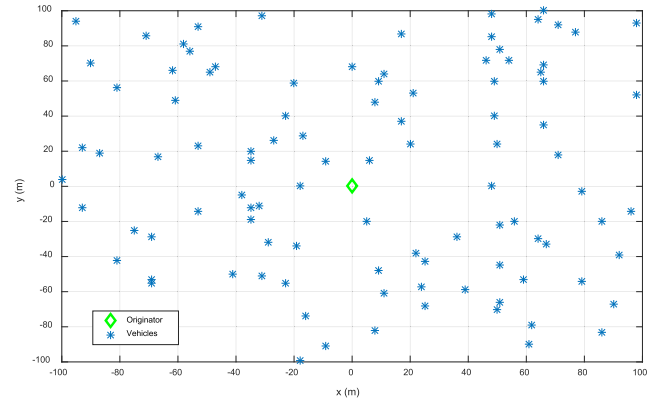


FIGURE 13. The placements of the vehicles and the originator in the case 2.

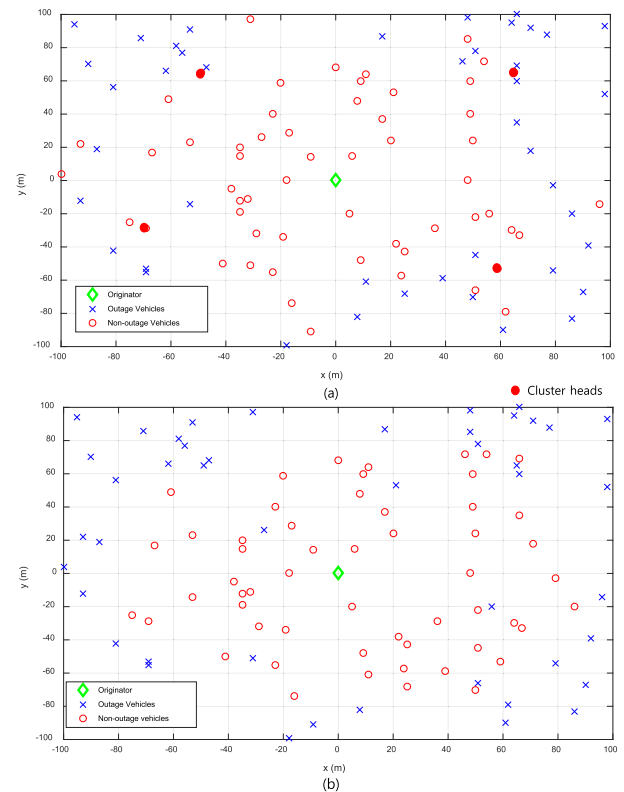


FIGURE 14. The comparison of the proposed and the conventional emergency alert broadcasts after the 1st broadcast in the case 2.

Figure 13 illustrates the placements of the vehicles and the originator in the case 2. Figure 13 shows that the 100 vehicles are randomly placed in the indoor area (uniform distribution). This figure also shows that the originator is located at the center (0,0) of the indoor area. The locations of the vehicles can be estimated using the technique of section II-B.

Figure 14 shows a comparison of the proposed and the conventional emergency alert broadcasts after the 1st broadcast in the case 2. Figure 14(a) exhibits the outage states for the proposed broadcast. This broadcast exploits the presented cluster diversity technique for rebroadcasts. In the 1st broadcast, the center originator broadcasts the alert



packet. Figure 14(a) reveals that the 57 vehicles correctly decode the alert packet. Therefore, the success rate is 57% in the 1st broadcast case. As shown in Figure 14(a), the 4 cluster heads are selected from the non-outage vehicles, which offer the cluster diversity in the 2nd broadcast. Figure 14(b) exhibits the outage states for the conventional broadcast, which just relies on the conventional carousel method [11] for rebroadcasts. Like the case of Figure 14(a), the center originator is also used for the 1st broadcast of the alert packet in Figure 14(b). The success rate is 55% in Figure 14(b). This reveals that the proposed and the conventional broadcasts provide almost same performance in the 1st broadcast case.

Figure 15 exhibits a comparison of the proposed and the conventional emergency alert broadcasts after the 2nd broadcast in the case 2. Figure 15(a) exhibits the outage states for the proposed broadcast. As shown in Figure 15(a), the success rate is 100%. This indicates that all the vehicles can correctly decode the alert packet within 2 broadcasts. This is due to the cluster diversity that the cluster heads of Figure 14(a) exploit in the 2nd broadcast. Figure 15(b) shows the outage states for the conventional broadcast. Unlike the case of Figure 15(a), there are still lots of outage vehicles even after the 2nd broadcast. In Figure 15(b), the success rate is just 68%. Therefore, more rebroadcasts are required in the case of conventional broadcast. This may cause a severe latency especially in the urgent emergencies.

Figure 16 illustrates the placements of the vehicles and the originator in the case 3. In order to better investigate the orig-

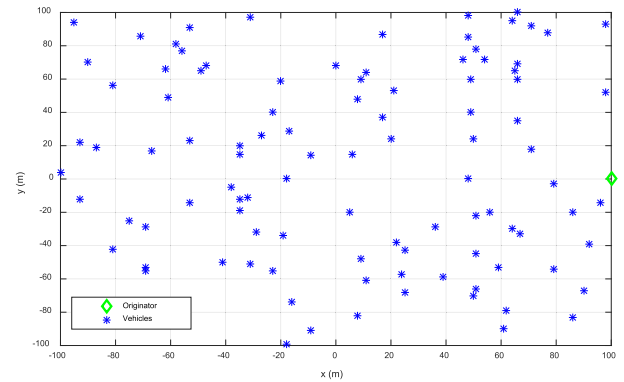


FIGURE 16. The placements of the vehicles and the originator in the case 3.

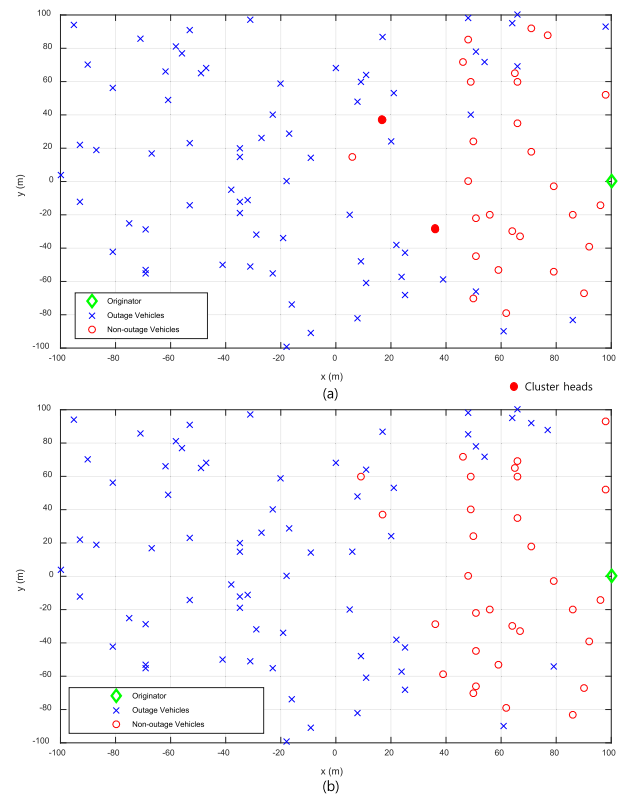


FIGURE 17. The comparison of the proposed and the conventional emergency alert broadcasts after the 1st broadcast in the case 3.

inator location effect on the broadcast performance, the locations of the 100 vehicles are same as those of the case 2. However, the originator is located at the edge (100,0) of the indoor area as shown in Figure 16.

Figure 17 exhibits a comparison of the proposed and the conventional emergency alert broadcasts after the 1st broadcast in the case 3. In the 1st broadcast, the edge originator broadcasts the alert packet. Figure 17(a) exhibits the outage states for the proposed broadcast. In Figure 17(a), the success rate is 29%. Note that there is no any non-outage vehicle in the left upper-area and left lower area. Therefore, only the 2 cluster heads are selected from the upper and lower non-outage vehicles, which also offer the cluster diversity

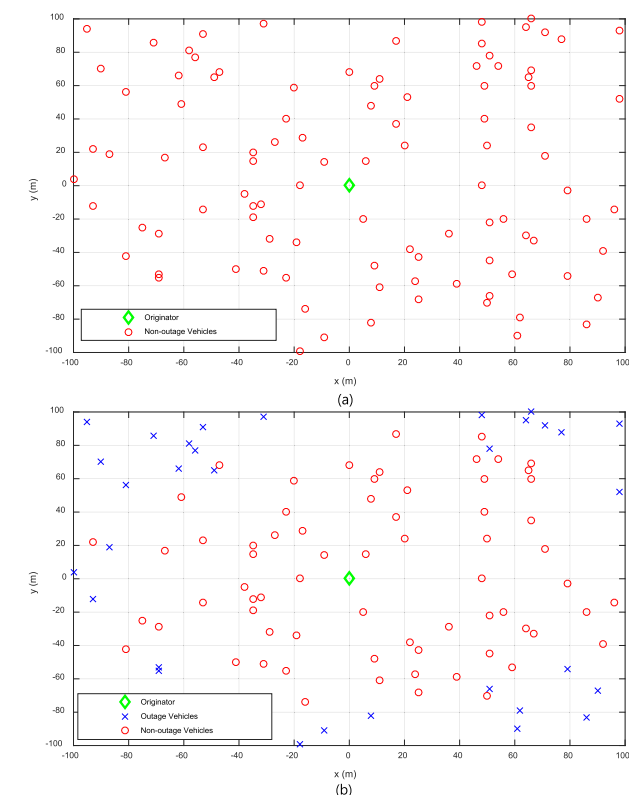
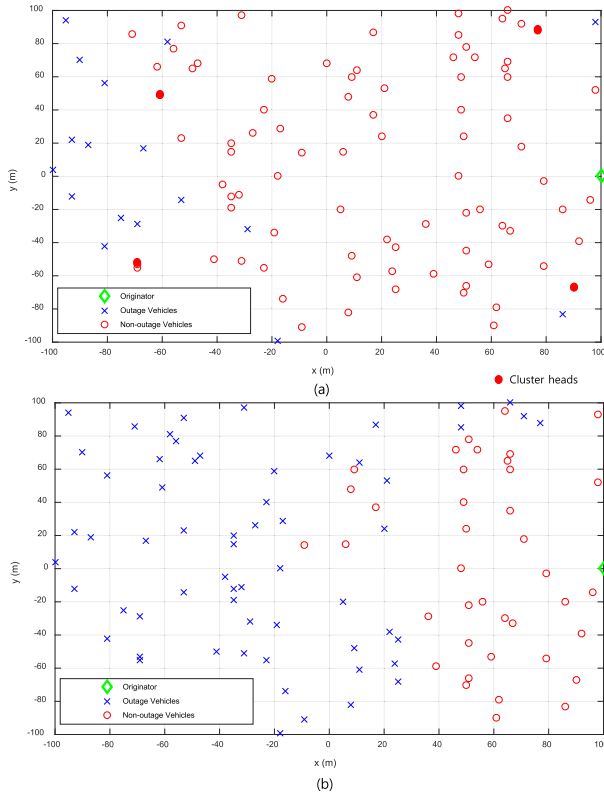


FIGURE 15. The comparison of the proposed and the conventional emergency alert broadcasts after the 2nd broadcast in the case 2.

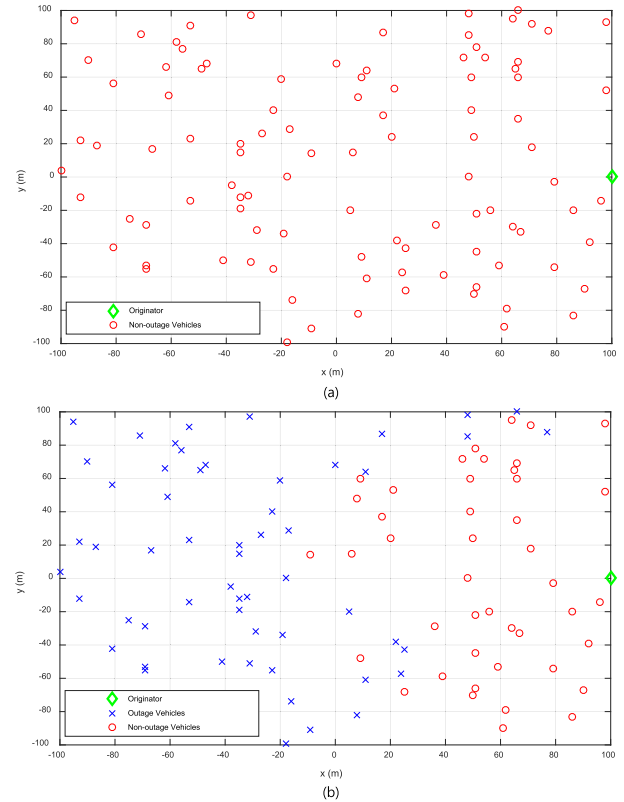


**FIGURE 18.** The comparison of the proposed and the conventional emergency alert broadcasts after the 2nd broadcast in the case 3.

in the 2nd broadcast. Figure 17(b) shows the outage states for the conventional broadcast. The success rate is 31% in Figure 17(b).

Figure 18 shows a comparison of the proposed and the conventional emergency alert broadcasts after the 2nd broadcast in the case 3. Figure 18(a) exhibits the outage states for the proposed broadcast. In Figure 18(a), the success rate is 83%. Using the 2 cluster heads of Figure 17(a), the cluster diversity has substantially increased the success rate. Figure 18(a) also reveals that the non-outage vehicles are more evenly distributed on the entire indoor area. Therefore, the 4 cluster heads can be selected from the non-outage vehicles for the 3rd broadcast, which is shown in Figure 18(a). Figure 18(b) exhibits the outage states for the conventional broadcast. Since the edge originator is still used for the rebroadcast, the success rate is just 39% in Figure 18(b).

Figure 19 exhibits a comparison of the proposed and the conventional emergency alert broadcasts after the 3rd broadcast in the case 3. Figure 19(a) shows the outage states for the proposed broadcast. In Figure 19(a), the success rate is 100%. This indicates that all the vehicles can correctly decode the alert packet within 3 broadcasts in the case of edge originator. Due to the cluster diversity of the 4 cluster heads [in Figure 18(a)], the proposed broadcast can achieve the success rate of 100%. Figure 19(b) exhibits the outage states for the conventional broadcast. Figure 19(b) does not show a noticeable increase in the success rate. In the case of conventional broadcast, the success rate is just 44%. Note that



**FIGURE 19.** The comparison of the proposed and the conventional emergency alert broadcasts after the 3rd broadcast in the case 3.

almost all the vehicles on the left area are still in the outage state in Figure 19(b). This may lead to a disastrous effect in the urgent emergency cases. Therefore, it is revealed that the conventional broadcast approach is not suitable for the case of edge originator especially when emergency alert broadcast is required.

## V. CONCLUSION

This paper presents the novel emergency alert broadcast approach for autonomous vehicles in indoor environments including smart buildings. The autonomous vehicles are assumed to make localization and make vehicular communications. The broadcast method relies on the proposed cluster diversity for rebroadcasts. Based on the cluster diversity, the alert broadcast significantly reduces the number of rebroadcasts, which allows a rapid delivery of emergency alerts to all the autonomous vehicles in indoor areas. The proposed cluster diversity consists of clustering and diversity combining. In order to effectively identify a cluster head, the cluster diversity approach utilizes the location information of autonomous vehicles. Whenever a cluster is determined, the corresponding cluster head is selected among the non-outage vehicles. The cluster head transmits the emergency alert message to the autonomous vehicles in the rebroadcast cases. Due to the selected cluster heads, the distance between transmitter and receiver is shortened in the rebroadcast cases. This leads to the considerable reduction of the number of rebroadcasts.

In order to further reduce the number of rebroadcasts, a diversity combining approach is proposed in this paper, which is based on the clustering. For each cluster, the same alert packet is orthogonally assigned to the corresponding frequency sub-band in one OFDM block. Therefore, the OFDM block includes the repeated alert packets. This enables the diversity. In the OFDM block, the orthogonal allocation also contributes to the avoidance of the interferences from the other clusters. In the received OFDM block, the autonomous vehicle extracts the emergency alert packet with the maximum power. Therefore, the vehicle receiver achieves a diversity gain, which is similar to that of the selection combining technique.

Experimental evaluation reveals the validity of the presented emergency alert broadcast method. The experimental results exhibit that the proposed cluster diversity can enormously reduce the number of rebroadcasts in the indoor environments. The results also show that the proposed approach profoundly outperforms the conventional carousel technique in terms of the number of outage vehicles in the rebroadcast cases in the indoor environments. Finally, the evaluation confirms that the proposed approach is very suitable for the emergency alert broadcast to autonomous vehicles in indoor environments.

## REFERENCES

- [1] V. Javidroozi, H. Shah, and G. Feldman, "Urban computing and smart cities: Towards changing city processes by applying enterprise systems integration practices," *IEEE Access*, vol. 7, pp. 108023–108034, Aug. 2019.
- [2] F. Pieri, C. Zambelli, A. Nannini, P. Olivo, and S. Saponara, "Is consumer electronics redesigning our cars?: Challenges of integrated technologies for sensing, computing, and storage," *IEEE Consum. Electron. Mag.*, vol. 7, no. 5, pp. 8–17, Sep. 2018.
- [3] X. Zhang, M. Pipattanasomporn, T. Chen, and S. Rahman, "An IoT-based thermal model learning framework for smart buildings," *IEEE Internet Things J.*, vol. 7, no. 1, pp. 518–527, Jan. 2020.
- [4] I. Jeon, M. Song, S. Chang, S. J. Choi, and Y.-T. Lee, "A signaling emergency alert system multiplexed with T-DMB channel for emergency alert service," *IEEE Trans. Consum. Electron.*, vol. 61, no. 1, pp. 16–23, Feb. 2015.
- [5] A. Ghosh, A. Maeder, M. Baker, and D. Chandramouli, "5G evolution: A view on 5G cellular technology beyond 3GPP release 15," *IEEE Access*, vol. 7, pp. 127639–127651, Sep. 2019.
- [6] M. Song, S. Chang, and Y.-T. Lee, "A wake-up consumer device for enhanced emergency alert service in T-DMB systems," *IEEE Trans. Consum. Electron.*, vol. 61, no. 3, pp. 286–294, Aug. 2015.
- [7] F. Meneghello, M. Calore, D. Zucchetto, M. Polese, and A. Zanella, "IoT: Internet of threats? A survey of practical security vulnerabilities in real IoT devices," *IEEE Internet Things J.*, vol. 6, no. 5, pp. 8182–8201, Oct. 2019.
- [8] *Technical Realization of Cell Broadcast Service (CBS), Release 16*, document 3GPP TS 23.041 V16.2.0, Dec. 2019.
- [9] *Signaling, Delivery, Synchronization, and Error Protection*, ATSC Standard A/331, Jun. 2019.
- [10] M. Kim and S. Chang, "A consumer transceiver for long-range IoT communications in emergency environments," *IEEE Trans. Consum. Electron.*, vol. 62, no. 3, pp. 226–234, Aug. 2016.
- [11] *Multimedia Broadcast/Multicast Service (MBMS) User Services; Stage 1, Release 15*, document 3GPP TS 22.246 V15.0.0, Jun. 2018.
- [12] M. Kim and S. Chang, "A novel receiver for reliable IoT communications based on ZigBee under frequency-selective indoor environments," *IEICE Trans. Fundam. Electron., Commun. Comput. Sci.*, vol. E100.A, no. 2, pp. 361–365, 2017.
- [13] E. Moradi-Pari, H. N. Mahjoub, H. Kazemi, Y. P. Fallah, and A. Tahmasbi-Sarvestani, "Utilizing model-based communication and control for cooperative automated vehicle applications," *IEEE Trans. Intell. Vehicles*, vol. 2, no. 1, pp. 38–51, Mar. 2017.
- [14] L. Zhang, Z. Zhao, Q. Wu, H. Zhao, H. Xu, and X. Wu, "Energy-aware dynamic resource allocation in UAV assisted mobile edge computing over social Internet of vehicles," *IEEE Access*, vol. 6, pp. 56700–56715, Oct. 2018.
- [15] M. Chen, T. Wang, K. Ota, M. Dong, M. Zhao, and A. Liu, "Intelligent resource allocation management for vehicles network: An A3C learning approach," *Comput. Commun.*, vol. 151, pp. 485–494, Feb. 2020.
- [16] L. Zhang, W. Cao, X. Zhang, and H. Xu, "MAC2: Enabling multicasting and congestion control with multichannel transmission for intelligent vehicle terminal in Internet of vehicles," *Int. J. Distrib. Sensor Netw.*, vol. 14, no. 8, Aug. 2018, Art. no. 155014771879358.
- [17] T. Li, M. Zhao, and K. K. L. Wong, "Machine learning based code dissemination by selection of reliability mobile vehicles in 5G networks," *Comput. Commun.*, vol. 152, pp. 109–118, Feb. 2020.
- [18] X. Liu, A. Liu, T. Wang, K. Ota, M. Dong, Y. Liu, and Z. Cai, "Adaptive data and verified message disjoint security routing for gathering big data in energy harvesting networks," *J. Parallel Distrib. Comput.*, vol. 135, pp. 140–155, Jan. 2020.
- [19] G. Kongara, C. He, L. Yang, and J. Armstrong, "A comparison of CP-OFDM, PCC-OFDM and UPMC for 5G uplink communications," *IEEE Access*, vol. 7, pp. 157574–157594, Oct. 2019.
- [20] D. Wang, Y. Cao, and J. Xing, "A note on 'a hybrid selection/equal-gain combining over correlated Nakagami-m fading channels,'" *IEEE Commun. Lett.*, vol. 15, no. 9, p. 925, Sep. 2011.
- [21] *Radio Resource Control (RRC) Protocol Specification, Release 15*, document 3GPP TS 38.331 V15.8.0, Dec. 2019.
- [22] Y. Yang, D. Fei, and S. Dang, "Inter-vehicle cooperation channel estimation for IEEE 802.11p V2I communications," *J. Commun. Netw.*, vol. 19, no. 3, pp. 227–238, Jun. 2017.
- [23] *Wireless LAN Medium Access Control(MAC) and Physical Layer(PHY) Specifications, Amendment 6: Wireless Access in Vehicular Environments*, IEEE Standard 802.11p-Part11, 2010.
- [24] E. Choi and S. Chang, "A consumer tracking estimator for vehicles in GPS-free environments," *IEEE Trans. Consum. Electron.*, vol. 63, no. 4, pp. 450–458, Nov. 2017.
- [25] E. Choi and S. Chang, "An adaptive tracking estimator for robust vehicular localization in shadowing areas," *IEEE Access*, vol. 7, pp. 42436–42444, Mar. 2019.
- [26] S. Haykin, *Adaptive Filter Theory*, 4th ed. Upper Saddle River, NJ, USA: Prentice-Hall, 2002.
- [27] I. Marsic, "Computer networks: Performance and quality of service," Rutgers, 2013.
- [28] L. Chen, Y. Gao, G. Chen, and H. Zhang, "Metric all-k-nearest-neighbor search," *IEEE Trans. Knowl. Data Eng.*, vol. 28, no. 1, pp. 98–112, Jan. 2016.
- [29] A. Goldsmith, *Wireless Communications*. Cambridge, U.K.: Cambridge Univ. Press, 2005.
- [30] Y. S. Cho, J. Kim, W. Y. Yang, and C. G. Kang, *MIMO-OFDM Wireless Communications With MATLAB*. Hoboken, NJ, USA: Wiley, 2010.



**SEKCHIN CHANG** received the B.S.E.E. and M.S.E.E. degrees from the Department of Electronics and Computer Engineering, Korea University, Seoul, South Korea, in 1991 and 1993, respectively, and the Ph.D. degree from the Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, TX, USA, in 2001. From 1993 to 1998, he was with the Electronics and Telecommunications Research Institute (ETRI), Daejeon, South Korea. He was also with Motorola, Inc., Austin, from 2000 to 2004. Since February 2004, he has been with the Department of Electrical and Computer Engineering, University of Seoul, Seoul, where he is currently a Full Professor. His current research interests include wireless emergency alert systems, the Internet of Things, real-time locating systems, embedded vehicle systems, and wireless communications.

• • •