Node-clustering communication method to improve QoS in V2X communications in crash warning applications

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Abstract: Crash Warning Application (CWA) for vehicle safety is expected one of the most important applications in smart city. CWA exchanges status information between all nodes by broadcast frames in V2X (Vehicle-to-Everything) communications. Since CWA has some QoS requirements, the number of nodes such as vehicles and pedestrians must be less than a certain value to avoid congestion. In order to accommodate more communication nodes in CWA, a novel cluster-based communication method is proposed. In this method, a cluster head estimates its members’ status and transmit them on behalf of the members instead of collecting members’ information with using additional spectrums. Members transmit correction frames if they hear unacceptable error in the estimation. Depending on the error value, congestion level is to decrease in frames simultaneously sent by cluster head but to increase in additional frames for the error correction. The proposed method is evaluated to show its effectiveness for the number of cluster members and error values (error probabilities).

Keywords: V2X, DSRC, IEEE802.11p, crash warning, congestion, clustering

Classification: Terrestrial Wireless Communication/Broadcasting Technologies

References

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1 Introduction

In recent years, Crash Warning Application (CWA) [1] is expected as one of ITS (Intelligent Transport Systems) applications for more safety vehicle transportation in Smart City. We focus on DSRC (Dedicated Short Range Communications) [2, 3] for V2X (Vehicle-to-Everything) communications. DSRC uses IEEE802.11p [4] as a MAC layer protocol, so the channel is accessed in a distributed manner complying CSMA/CA as the same as that in IEEE802.11a. For CWA to know surrounding situations and prevent traffic accidents, communication nodes such as cars and pedestrians exchange information frames which include own node status such as ID, time, location, velocity. Nodes such as cars periodically advertise their information by broadcasting the frames. Nodes also must satisfy specific QoS (Quality of Services) requirements in V2X communications for CWA. Specifically, nodes must receive 10 or more frames before 2.5 s∼9.5 s prior to potential crashes [5, 6]. It is more difficult to satisfy the requirements when more nodes exist due to the increasing interference signal strength and frame traffic congestion. Therefore, Node Accommodation Capacity (NAC) that is defined as the maximum number of nodes that can satisfy the requirements could not be reached at the desired capacity.

To increase NAC, cluster-based communication methods can be applied. The methods consist of three elements; (1) multiple nodes form clusters, (2) cluster heads collect all data frames of nodes in own cluster (members) in Intra-Cluster...
communications, and (3) only cluster heads transmit the frames on behalf in Inter-Cluster communications. The methods can decrease the number of frames sent at the same time in Inter-Cluster communications so that interference signal strength would be reduced. The conventional cluster-based communication methods [7, 8, 9], however, requires additional spectrums [7, 9] or power control mechanisms [8, 9] for Intra-Cluster communications. We here assume we cannot obtain additional spectrums nor power control mechanisms. Thus, we propose a novel cluster-based communication “CLASES (CLustering Algorithm with meSsage EStimation)” [10] that uses tiny Inter-Cluster communications without additional spectrums nor power control mechanisms for increasing NAC. Since the proposed method uses estimation schemes, we describe the procedures of the proposed method as well as describe how estimation error effects on NAC.

2 CLASES: CLustering Algorithm with meSsage EStimation

2.1 Ideas of CLASES

The proposed method does not explicitly communicate with cluster members. Instead, a cluster head and cluster members contribute to an estimation process. Two key ideas for the estimation process are as follows.

A) Estimation by a cluster head

The first idea is an estimation. In order to obtain own members’ current status information without Intra-Cluster communications, a cluster head estimates it along with physical laws (i.e. physics relationships between location and velocity, etc.) from their past information. In other words, it estimates the information after a few milliseconds.

All nodes can hear and must hear other nodes’ frames sent in broadcast mode. After estimating the members’ current status information, the cluster heads transmit the same number of frames as members on behalf of the members. This results in the reduction of collision probability and the amount of interference signal strength because the upper limit of simultaneously sent frames is reduced from the number of nodes to the number of clusters.

B) Estimation Error Correction by the cluster members

The second idea is an error correction. The estimated information might contain some errors, so the proposed method needs a mechanism to correct these errors as follows. If a member detects unacceptable estimation error in a frame sent from the cluster head, the member transmit a correction frame which conveys the measured, i.e. correct information. The error correction frames are only sent for larger error than acceptable one.

We will not discuss how much error probability of the estimation should be observed. The accuracy of the estimation depends on a behavior of each vehicle and the past information of the vehicle. The broadcasted information includes enough data such as direction, velocity and acceleration. Then, it seems much easier to estimate accurate locations of the vehicles in 100 msec than the crash estimation in which all nodes in CWA are required to estimate in advance whether to collide with another node even before a few seconds. Unacceptable large errors may occur in cumulative estimations. We assume that the probabilities of the
unacceptable error are small and error correction frames are sent in a few percentages over all frames in our evaluations.

2.2 Example of CLASES
We show an example of the proposed method by 5 nodes (A∼E) as the following. Here, Info(X, t) shows a measured information frame that node X transmits at time t and Info(X', t) shows an estimated information frame of X.

Step 1) Cluster Making and Cluster Head Decision
Although it is not our scope to show efficient cluster making process, we just show a sample making process. Before completing to form the cluster, the followings occur. Node A sends Info(A, t) only, node B who is not in a cluster member hears it and knows that A belongs to no clusters. B sends Info(B, t + 100) and Info(A', t + 100). Note that Info(A', t + 100) is an estimated value of Info(A, t + 100), which in this case B estimates. All nodes know that B and A form a cluster because B sent Info(A', t + 100). This process is repeated in every opportunity of information sending events, 100 msec. In case of that the maximum cluster member is five, this process ends at node E sending Info(E, t + 400), Info(D', t + 400),..., Info(A', t + 400) and it takes 500 msec to form the cluster.

We suppose that effects on the system performance from this process is not so large, because this cluster making process is not expected to frequently occur. As long as members can hear each other frames, i.e. members are within about 300 m radius range, the cluster can survive regardless of positions of the members. Thus, the process occurs much less than that of periodic broadcasting, every 100 msec. Note that since cluster members does not need to be placed close to each other, it is desired to form a cluster with considering proximity in order to keep the cluster for longer time.

Then, nodes elect a cluster head. For example, we may make a rule that a cluster head is chosen in order from the node joined the cluster earlier. In the following steps, we discuss the case that A is their cluster head.

Step 2) Estimation
In this step, cluster head A estimates member’s status information. At time t, A estimates the status information of the members (B, C, D, E); Info(B', t), Info(C', t),..., Info(E', t). In order to estimate it, A can use their past status information such as information at time t/C0, Info(B, t/C0),..., Info(E, t/C0). A can obtain them by listening to their frames before time t. It should be noted that some estimated status information is likely to contain the unacceptable errors.

Step 3) Inter-Cluster Communications
In step 3, A broadcasts the frames conveying own measured information Info(A, t) or members’ estimated information Info(B', t),..., Info(E', t) as shown in Fig. 1(a). All nodes, however, may still obtain status information remaining unacceptable error in this step.

Step 4) Estimation Error Correction
In step 4, B∼E must listen to A’s broadcasted frames in order to correct own information. For example, E’s status information Info(E', t) contains an unacceptable error, and then E broadcasts Info(E, t) by itself as shown in Fig. 1(b).
The cluster repeats Step 2 to Step 4.

### 2.3 Characteristics of CLASES

The proposed method has two characteristics about NAC.

The first characteristic is that NAC increases at first as the number of cluster members increases, then decreases. This occurs because of a tradeoff between interference power reduction and parallel transmission reduction [10].

The second characteristic is that NAC decreases as the more amount of the error correction frames to cause severer congestion. This occurs by two factors. Firstly, more possibility of occurring unacceptable error causes to transmit them more frequently. Secondly, they are also generated as the number of cluster members increases. This is because the number of times of estimation increases. Cluster heads transmit 5 estimated information \((B', D', F', H', J')\) in the case in Fig. 2(a), but they increase up to 9 estimated information \((B'~J')\) in the case in Fig. 2(b). Therefore, the number of times of estimation increases to 9 from 5.

Eventually, NAC generally increases at first then decreases as the number of cluster members increases. Moreover, it decreases when the unacceptable error occurs the more frequently. The decreasing width increases as the number of cluster members increases.

![Fig. 1. Abstract images of Step 3 and Step 4.](image)

![Fig. 2. Abstract images of 2 members’ cluster and 10 members’ cluster](image)
3 Node accommodation capacity

Due to space limitations, evaluation models refer [11] except for the following assumptions. An unacceptable error is introduced as the rate of error correction frames to frames conveying estimated information, i.e. *error correction occurrence rate (ECOR)*. ECOR is set enough small, a few percentages.

Fig. 3 shows NAC of the proposed method. Its horizontal axis is the number of cluster members and its vertical axis is NAC. As shown in Fig. 3, NAC of the proposed method increases more than NAC of the non-cluster method (i.e. 1 member cluster) by 19% when ECOR is 2% and the number of cluster members is 9 nodes. In the case of no error correction frames, it is more than NAC of the non-cluster method by 24% when the number of cluster members is 11 nodes. On the other hand, it is less than NAC of the non-cluster method, when ECOR is over 14%.

4 Conclusion

We proposed a novel cluster-based method “CLASES”, and then showed the proposed method is effective for CWA with V2X communications.

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