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主　論　文　の　要　旨

論文題目　Decentralized Cross-layer Congestion Controls for DSRC-V2X and PC5-based Cellular-V2X Mode 4 in Crash Warning System
(衝突警告システムにおける自律分散型車車間・歩車間通信のためのクロスレイヤ無線輻輳制御技術の評価・検討)

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論 文 内 容 の 要 旨

Decentralized vehicle-to-everything (V2X) potentially supports various road traffic problems, like traffic accidents and traffic jams. Such V2X is applied to the crash warning system (CWS) to assist drivers in intelligent transportation systems (ITS) for smart mobility. In CWS, each node (e.g., a car or a pedestrian with V2X equipment) periodically broadcasts its data frames, including its location, speed, and direction. CWS warns the user based on its potential crash risks estimated from the received information. CWS requires reliable V2X communications to obtain enough frames for accurate warnings; in other words, the frame reception reliability of V2X plays a key role in using CWS practically. CWS can cover nodes in blind spots of existing sensors under the requirements, like radars and cameras. Thus, CWS improves mobility safety levels.

Two decentralized V2X standards have been actively studied: dedicated short range communications (DSRC) and PC5-based cellular-V2X mode 4 (called mode 4). These protocols have random access protocols in their medium access control (MAC) layer without any infrastructures, like base stations. This infrastructure-less characteristic strongly supports CWS in the early deployment stages because communication costs with base stations and implementing base stations are unnecessary to use the V2X technologies anywhere. DSRC implements a basic random access protocol, carrier sense multiple access with collision avoidance (CSMA/CA), and mode 4 implements an advanced random access protocol, sensing-based semi-persistent scheduling (SPS). Mode 4 provides more reliable communications than DSRC. In contrast, mode 4 commercially consumes higher costs than DSRC because the standard is still being developed. Practically, adopted technologies depend on industry requirements or every country's networks. For these reasons, advancing both protocols are necessary.

However, such V2X potentially experiences a channel congestion problem. Such a problem occurs in crowded environments, like intersections. The problem causes frame collision errors more frequently than in non-congested cases, and as a result, CWS may fail to satisfy its CWS requirements. Some related works focused on channel congestion as follows. Few related works have focused on the congestion problem considering the number of obtained frames required in CWS; in particular, no related works have evaluated the performance characteristics of mode 4 under its channel congestion by CWS requirements. Some related works also proposed the decentralized congestion control (DCC) for V2X. Unfortunately, most of the existing DCC methods reduce the number of transmitted frames to mitigate channel congestion. The mechanism efficiently decreases frame collision errors but also reduces the number of received frames per node. As a result, no related works have essentially addressed channel congestion in the use-cases of CWS. Mitigating channel congestion is necessary to use CWS practically.

The author studies the channel congestion problem of the decentralized V2X in this paper. To this end, the author challenges the following three contents: proposing a congestion control for DSRC, evaluating the performance of mode 4 under channel congestion in CWS, and proposing a congestion control for mode 4. The proposed congestion controls focus on improving the random access mechanisms without decreasing the number of obtained frames, unlike the existing congestion control methods. The author then proposes cross-layer approaches for the congestion controls, i.e., decentralized cross-layer congestion controls; for example, the author focuses on application-MAC cross-layer approaches and physical-MAC cross-layer approaches for the V2X standards.

First, the author proposes a node-clustering method for DSRC, CLASES, which incorporates the application layer with the MAC layer. In CLASES, multiple nodes form a cluster, and then only each cluster head transmits frames of all the cluster members on behalf of members; data in frames of the members comply with estimated data from their past frames. The proposed method enables nodes to access the V2X channel efficiently and thus mitigates channel congestion. The simulation results highlighted that CLASES improved 27% better performance under channel congestion than the current DSRC. In summary, this research contributes to improving V2X performance without reducing the amount of information under the DSRC channel congestion through the efficient node-clustering method for CWS use-cases.

Second, this paper presents the performance degradation of mode 4 due to channel congestion. The author evaluates the performance in both fundamental and realistic node density, strongly related to the channel congestion. Through the simulations, mode 4 achieved 55% lower performance than the required performance at a large intersection. These results supported that mode 4 needs congestion controls. In summary, this study contributes to revealing performance characteristics under channel congestion and highlighting performance degradation of the current mode 4, compared with the CWS requirements.

Finally, the author proposes a method with the non-orthogonal multiple access (NOMA) for mode 4, called DB-NOMA, a physical-MAC cross-layer congestion control. DB-NOMA contains two methods. One of them is a frame relaying method using NOMA. In the proposed relaying method, each node broadcasts its own frame and the relayed frame of another node in a downlink NOMA manner. The other is a parallel transmission using NOMA, called SPS-NOMA. In SPS-NOMA, each node selects a spectrum resource based on sensing-based SPS, a suitable resource selection for NOMA. Then, multiple nodes simultaneously transmit their frames in an uplink NOMA manner. NOMA supports multiple nodes to access a spectrum resource at the same time and thus mitigates channel congestion. The proposed relaying method improved 94% better performance than the current mode 4. SPS-NOMA also boosted 38% better performance than the current mode 4. In summary, this research contributes to proposing NOMA for the decentralized V2X and mitigating the channel congestion problem of mode 4 while keeping the amount of information.

Through this paper, the author contributes to mitigating the congestion problem of CWS without decreasing the amount of information and extending decentralized congestion controls for both V2X standards to cross-layer congestion controls. First, the author demonstrated that the proposed methods supported more wide CWS use-cases without reducing the amount of information, unlike the existing DCC approach. Second, this paper strongly supports next-generation wireless networks, like the fifth-generation (5G) V2X networks, through studying advanced node-clustering method and decentralized NOMA. The proposed congestion controls are also expected to support other networks for Smart city.