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Collision correction using a cross-layer design architecture for dedicated short range communications vehicle safety messaging

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ABSTRACT

This paper presents a new physical (PHY) and medium access control (MAC) cross-layer design frame collision correction (CC) architecture for correction of Dedicated Short Range Communications (DSRCs) safety messages. Conditions suitable for the use of this design are presented, which can be used for optimization. At its basic level, the CC at the PHY uses a new decision making block that uses information from the MAC layer for the channel estimator and equalizer. This requires a cache of previously received frames, and pre-announcing frame repetitions from the MAC. We present the theoretical equations behind CC mechanism, and describe the components required to implement the cross-layer CC using deployment and sequence diagrams. Simulation results show that especially under high user load, reception reliability of the DSRC safety messages increases and PER decreases.
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1. Introduction

Dedicated Short Range Communications (DSRCs) will enable vehicles to have active safety applications, one of which is periodic broadcast of vehicle's heart beat messages [1–3]. These messages will provide vital information (e.g., location, direction, and speed) of the vehicle as well as safety and emergency information (e.g., airbag deployment and accident report) to the surrounding vehicles in order to warn drivers or assist in reacting to an emergency situation. The effectiveness of the active safety applications depends on reliability of transmission of emergency messages. That is why reliable transmission of the emergency and safety messages has the upmost importance in the DSRC system. In order to improve the reliability of transmissions, repetition schemes are employed by the safety and emergency message broadcast medium access control (MAC) protocol of DSRC. These protocols repeat the messages based on scheduling and scrambling mechanisms, such as synchronous fixed repetition (SFR), synchronous p-persistent repetition (SPR), or positive orthogonal codes (POC) [4,5] to improve reception probability (i.e., probability of successful reception) of the vehicle safety messages. However, there is no feedback (i.e., acknowledgement or negative acknowledgement) in the MAC protocol and the transmitting node assumes that at least one of the repeated messages is successfully received. Broadcasting frequency, which depends on vehicle density and number of repetitions, and vehicle mobility can significantly affect the reliability of the reception and reduce the probability of successful message transmission due to message collisions [6]. Collisions in such random MAC schemes are not completely avoidable, especially when a large number of vehicles in the transmission region are present and number of repetitions is large. It is shown in [6] that increasing number of repetitions does not always

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contribute to increasing probability of success. That is why innovative techniques must be introduced to improve the probability of success to take full advantage of active safety applications that would be provided with DSRC deployment. One of such innovative techniques is to introduce cross-layer design (CLD) in the receiver architecture to improve the reception probability.

In this work, CLD is utilized to improve the probability of transmission success in emergency messaging scheme, where physical layer (PHY) and MAC layer interacts to recover emergency messages even there are message collisions. If one of the collided messages has been received successfully prior to collision event, the other message in the collision, which was not successfully received, can be recovered with knowledge of the successfully received message. Hence, the probability of success will be significantly improved. The CLD is modelled in the simulator and tested in various channel conditions. It is shown that it is most effective in high repetition scenarios.

The remaining of this paper is organized as follows: Section 2 provides a brief literature review and further discusses aspects relating to our work; Section 3 presents models, methods, descriptions of our complete CLD architecture for the purpose of allowing our system to be reproduced; Section 4 provides simulation parameters, describes our method of testing, and provides simulation results and analysis; and finally Section 5 provides concluding remarks about our design and results it achieves.

2. Related work

Our proposed system uses CLD between the MAC and PHY, re-transmissions with warning of vehicle safety messages. Related works to these aspects are discussed in this section.

Vehicle-to vehicle (V2V) communications offers effective and efficient applications for cooperative driving, safety and emergency applications. For these applications, particularly for safety and emergency applications, reliability and delay of messages require novel solutions to combat challenging V2V communication channels. Among those solutions, cooperative diversity [7], network coding [8], and CLD are most prominent. Cooperative diversity achieves the diversity gain by allowing surrounding nodes to relay messages for others in single transmitter antenna and single receiver antenna systems [7]. This method has been applied to V2V systems and shown to be effective in improving communication reliability [9,10]. The challenges in the cooperative diversity schemes are relay node selection, relay node coordination and type of relaying methods. Network coding takes advantage of wireless broadcast medium to achieve its coding gain [11] and has been applied to V2V communication systems. Employing network coding requires strict scheduling mechanism which cannot necessarily be possible to provide an effective solution. The challenges required for deploying cooperative communication and network coding necessitates an overhaul of the exiting V2V communication standards and transceivers, which may take a significant amount of time. On the other hand, CLD techniques are largely transparent or only require minor modifications in the available standards. The main challenge for them is to be able to identify and apply correct interactions between layers at the transmitter and receivers. CLD has been gaining popularity in wireless communication systems because of their effectiveness and efficiency [12–14]. CLD deviates from conventional independent network layer paradigm and allows receiver to utilize some information and parameters available in other layers to optimize their operation. For example, congestion information in the MAC layer utilized to improve routing performance of network layer in wireless ad hoc networks [15]. Since CLD provides interactions among the layers, it could also be unstable if not carefully designed. Nevertheless, when CLD is carefully implemented, it offers significant increases in wireless system performance.

A survey of CLD techniques can be found in [12], which talks about different ways to implement CLD in wireless communication systems. Our approach involves both direct communication between layers, and a shared database. CLD of mobile ad hoc networks (MANET) discussed in [13] provides a discussion and methodology for how CLD can be utilized across layers of the mobile communication stack. MANET is very similar to vehicle communications because of the mobility of the nodes, while MANET's focus is more geared towards internet connectivity than DSRC's main objectives. Our design is hence focused on improving DSRC's safety messaging. Authors in [16] make the argument that in wireless networks dealing with repetition messages, initial repetitions can be used to cancel out interference, which they call known interference cancellation (KIC). We also have the same philosophy for our proposal, but our work focuses on DSRC safety messaging as an application of KIC. In [17], ZigZag decoding corrects frames by utilizing the asynchronicity between collisions in repetitions to construct an error free frame. In our system, the safety messages are synchronous and hence collisions result in full frame corruption, which means the ZigZag method is not feasible in this study. Ref. [18] presents advantages of using CLD for DSRC and in this work we propose architecture necessary for implementing a CLD design. This is the first CLD MAC and PHY that specifically targets improving reliability of repetition based safety messaging in DSRC. In addition, our MAC layer uses repetition based transmissions of safety messages similar to [4,5,17]. Here repetition broadcasts are used to improve reliability of messages. The proposed system also uses repetition based broadcasting, but acts to correct collisions of these repetitions.

The standard DSRC receiver's PHY [2] consists basically of guard interval removal, fast Fourier transform (FFT), channel estimator (CE), equalizer, pilot removal, demodulator, de-interleaver, and decoder blocks shown in Fig. 1. These blocks are standard IEEE 802.11p [2], for the DSRC orthogonal frequency division multiplexing (OFDM) PHY. We focus on the CE and equalization blocks in this work; hence these blocks are described further along with our design in the next section. The PHY receiver passes the decoded frame to the MAC layer for validation of the MAC frame for passing to higher layers. Rayleigh fading, low signal to noise levels and collisions with other frames are

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