Chapter 10
Synchronous Relaying in Vehicular Ad-Hoc Networks

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ABSTRACT

In this paper, the authors propose a simple concept for emergency information dissemination in vehicular ad-hoc networks. Instead of competing for the shared wireless medium when transmitting the emergency information, the authors’ proposed method requires nodes to cooperate by synchronizing their transmissions. The proposed scheme is backward compatible with IEEE 802.11p carrier sense multiple access with collision avoidance. The authors also briefly address some of the implementation issues of the proposed scheme.

1. BACKGROUND AND MOTIVATION

In July 2010 the IEEE 802.11p standard (IEEE Computer Society, 2010) has been ratified, which specifies physical (PHY) and medium access control (MAC) extensions to provide wireless access in vehicular environments. The 802.11p MAC layer adopts the enhanced distributed channel access (EDCA) based on carrier sense multiple access with collision avoidance (CSMA/CA). According to the EDCA protocol the medium is slotted and stations compete for channel resources using different interframe spacing (IFS) intervals and contention window (CW) sizes. If the channel is free during the whole duration of the IFS interval a node is allowed to transmit. If the medium becomes occupied during the sensing, a node randomly chooses the backoff counter and defers its transmission attempt. When the channel is free the counter is decremented each time slot. The sizes of both the IFS interval and the CW depend on the type of the message to be transmitted, i.e., the higher the priority of a message is the shorter these values are. Assigning priorities in this way the MAC protocol ensures that the critical messages (i.e., those, notifying about safety-of-life hazards, accident in a close proxim-
ity of a node, etc.) have relative priority over the infotainment-related ones. This results in lower delivery delays and higher delivery probabilities of critical information. Nodes having packets of the same priority compete for transmission using the same IFS and CW.

In this paper we are concerned with the dissemination speed and coverage of emergency messages, i.e., those of utmost importance. Having safety in mind, for a protocol delivering such kind of information we can stipulate two requirements. First of all, emergency information needs to be spread out to all vehicles in a certain neighborhood, \( h \), of a car detecting the hazard. This geographic area may include infrastructure nodes that may disseminate notifications further using wide area wireless networks such as cellular systems. Secondly, emergency messages need to be disseminated as quickly as possible. CSMA/CA protocol which has been standardized in IEEE 802.11p is far from the optimal solution for these problems due to the inherent properties of random access.

Consider an arbitrary road environment crowded with vehicles equipped with the IEEE 802.11p on-board units (OBU) and concentrate on what happens just after a detection of a hazard. According to this scenario a number of vehicles compete for wireless media trying to disseminate critical information. As soon as one of them gets access then some nodes in its coverage area become notified and in their turn start to compete for the channel for further transmissions. Different probabilistic approaches to divide the numerous retransmissions of different nodes in time domain to prevent broadcast storm and to increase the efficiency of random accessing are proposed. Among them Emergency Message Dissemination in Vehicular environment (EMDV) (Torrent-Moreno, Mittag, Santi, & Hartenstein, 2009) is one of the well-known location-based forwarding. However, the efficiency of all these approaches depends on the performance of one-hop IEEE 802.11p broadcasting, which is briefly evaluated.

Assuming that the CW is constant the probability of choosing a slot in CSMA/CA protocol is approximated by \( 2/(W+1) \), where \( W \) is the size of the CW (see e.g., Bianchi, 2000). The probability that one or more nodes choose a certain slot \( i \) together with a given node and the packet transmission would result in a collision is given by \( r(W,N)=1-(1-2/(W+1))^{N-1} \), where \( N \) is the overall number of nodes. Taking into account that a packet can be lost as a result of insufficient signal strength with probability \( p \) and noticing that it is independent of the collision probability we get the following equation for probability of incorrect packet reception in exactly one transmission attempt.

\[
r(w,N,p) = 1 - \left(1 - \frac{2}{W+1}\right)^{N-1} (1 - p)
\]

Behavior of \( r(W,N,p) \) as a function of the number of competing nodes, CW size, and probability \( p \) is illustrated in Figure 1. Analyzing it one may observe two unwanted dependencies existing in \( r(W,N,p) \). First of all, for small CW size, \( W \), and negligible loss probabilities caused by channel conditions (\( p=0 \)), the probability of incorrect packet reception is close to 1. Since the window size is rather small for the distribution of emergency information the protocol is expected to perform poorly in the congested environments. Traffic accidents frequently lead to jams increasing the density of nodes in the local neighborhood. Since no acknowledgments are sent by the receivers of the broadcast messages their successful delivery is not guaranteed. Retransmissions may improve loss performance of the system; however, this improvement comes at the expense of higher delivery delays.

The second upsetting feature of IEEE 802.11p MAC protocol is that the presence of a number of nodes having the same emergency data to distribute does not positively affect the probability of packet delivery. Transmitting nodes do not