Cooperative Multi-channel Dissemination of Safety Messages in VANETs

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***Abstract*— IEEE 802.11p-based wireless access in vehicular environments (WAVE) multi-channel communication introduces communication clusters which limits on the dissemination efficiency of broadcast applications such as safety messaging. This paper proposes cooperative multi-channel information dissemination (CMD) which follows a channel coordination approach where the coordinator is selected based on the least average distance (LAD) to all service channels with the goal of relaying the emergency message to other service channels with minimum delay. On receipt of high priority emergency messages, each selected channel coordinators switches to a defined service channel and broadcasts the emergency message to it members. In the CMD approach, each vehicle assumes a single radio and the number of channel coordinators in each service channel cluster is determined based on the available service channels advertised and LAD to the advertised service channels. Computer simulations show that the proposed CMD performs well in terms of dissemination delay and dissemination rate.**

Keywords— IEEE 802.11p/WAVE, vehicular ad hoc networks, channel coordination, cooperative message dissemination.

I. Introduction

The IEEE 802.11p-based wireless access in vehicular environments (WAVE) defines multi-channel communications in vehicular environments and is grounded on the urge that now and in the future, vehicular networks should be able to access a diversity of services in several contexts. Some of these include location, situation, and on-demand contexts. This phenomenon has been coined as in-vehicle infotainment in vehicular communication studies [1]. To achieve this increasing interest, out of the seven channels defined in [2], six 10 MHz service channels in the 5.9 GHz frequency band have been reserved for this purpose.

By default, safety message communication is designed for propagation only in the WAVE control channel interval (CCHI) where all vehicles have channel access. However, considering the IEEE 802.11p/WAVE standard in a raw sense as-it-is, in the service channel, there is restrictive access to only the channel a vehicle is tuned to. This is a limitation to the dissemination of high priority safety messages to all vehicles during this phase of the synchronization interval. Therefore inter-channel communication techniques need to be designed for this case. Given the critical nature and sensitivity of safety message applications, the design for such protocols should meet a strict minimum delay requirement as much as possible while communicating across channels.

This paper proposes a cooperative multi-channel information dissemination (CMD) scheme which makes use of channel coordination. Using simulations, the proposed CMD performs well in terms of dissemination delay and dissemination rate compared to WAVE-enhanced safety message delivery scheme (WSD) [3]

The remainder of this paper is organized as follows. Section II describes related work on the multi-channel protocols for information dissemination in VANETs. Section III describes the proposed CMD system model. Section IV then shows the simulation analysis and comparisons of the proposed CMD with WSD. The conclusion is given in section V.

II. Related Work

A vast number of studies focusing on safety in vehicular ad hoc networks (VANETs) have put much emphasis on messaging in the control channel by use of adaptive channel interval and data rate techniques, broadcast storm mitigation techniques [4, 5], and clustering [6] among others. However in the interest of this study, this section shows studies whose attention have mainly been on utilising the service channel phase of the synchronisation interval for safety. By so doing, the intention of such studies have a motive of caring for dissemination of high priority safety messages when the service channel phase is active thereby enjoying the benefit of utilising the entire synchronization interval (SI) for safety messaging.

Ghandour *et al.* [3] proposed a WAVE-enhanced safety message delivery scheme (WSD) which aims at broadcasting event driven high priority messages to all service channels with the aim of minimizing the delay to reach a neighbour. At each node, WSD first operates in the CCHI to collect information from neighbour nodes through hello messages in order to formulate a simple data set of all available service channels and the participating nodes. In case there is a high priority message event trigger while in each service channel

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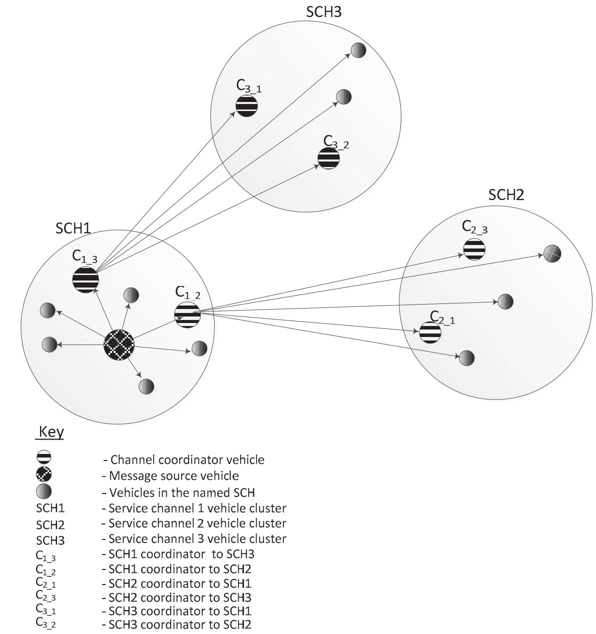

Fig. 1. Logical view of the CMD structure.

interval (SCHI), the channel with the least average ratio of the channel average delay and number of nodes is first tuned to by the vehicle affected for message dissemination. The channel switching continues in the order of the least ratio until all service channels are exhausted. It is worth noting that the WSD protocol puts emphasis on disseminating information to the neighbors with minimum delay but does not consider the dissemination delay to all the vehicles in the other channels.

Joo *et al.* [7] proposed a scheduling algorithm for high priority message dissemination (SAEMD) which operates by selecting and switching to a channel belonging to the nearest vehicle. Similar to WSD in [3], SAEMD uses a data collection routine in the CCHI and uses the separation distance data for deciding on the nearest vehicles hence the next service channel to be tuned to for information dissemination.

In contrast to the presented multi-channel approaches, the CMD protocol follows the channel coordination principle where the coordinator is selected using a distance-based selection approach and operates in the both the channel cluster domain and the coordination domain to meet the delay constraint requirement in safety message dissemination.

Abboud *et al.* [8] presented a cluster based broadcasting procedure which relies on relay nodes in VANET's to improve on emergency message delay. It is obvious in their work that they do not consider multi-channel communications as multi-channel communication requires scheduling which may additionally need knowledge or data collection of vehicles states relating to position and speeds. The proposed CMD addresses multi-channel communications in VANETs and uses acquired knowledge from the CCHI.

III. Cooperative Multi-channel Message Dissemination Protocol (CMD)

Fig. 1 shows the logical message dissemination process in CMD which can be expressed in the following three major steps.

1) A vehicle with a safety message to transmit while in the SCH broadcasts the message in its SCH.

2) The channel coordinator in the SCH receives the broadcast, switches to its determined coordinating service channel and forwards it by broadcasting the message.

In Fig. 1, it is assumed that only three service channels SCH1, SCH2, and SCH3 were advertised during the CCHI. Each vehicle belongs to a cluster identified by the service channel it is tuned to. The source vehicle in SCH1 broadcasts the message to all its channel members which also includes the channel coordinators c_{1_2} and c_{1_3}. The channel coordinators then relay by first switching to their determined service channels SCH2 and SCH3 respectively and then broadcasting the message.

A. Channel Coordinator Selection

For purposes of this study, the vehicles selected the advertised SCH's in the CCHI in a random manner. Each vehicle while in the CCHI receives and selects a service channel from the WAVE service advertisements (WSA) and also receives and transmits location information together with their selected service channel. With the location information received and expected SCH to be used by the transmitting vehicle in every instance, each receiving vehicle computes the separation distances in relation to each SCH with the objective of finding the least separation distance to vehicles expecting to tune to a specific SCH.

Considering each SCH as a cluster, a channel coordinator vehicle in an SCH cluster to another SCH cluster is such that for all vehicles in a given cluster, it has the LAD of connectivity to nodes on the other service channels. The channel coordinator selection model can be formulated as

$$(\exists c_{k\_z} \in k) : (\forall d_{i\_z}, (d_{c\_z} < d_{i\_z})) \qquad (1)$$

where $i = 1, ..., m$. m is the maximum number of vehicles in SCH k. c_{k_z} represents a channel coordinator vehicle in service channel k, z represents the SCH to switch to, d_{i_z} represents the average separation distance to nodes in each advertised channel z from vehicle node i, and d_{c_z} is the minimum average separation distance of vehicle c to other vehicles in the advertised channel z.

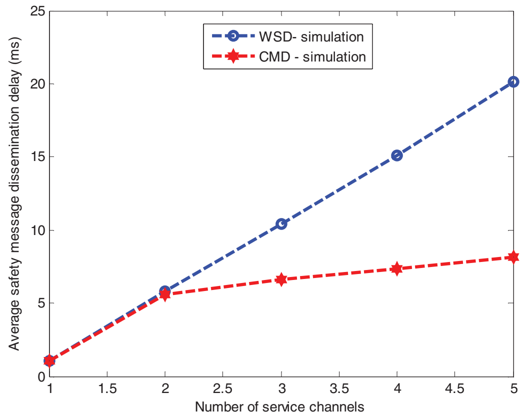

Fig. 2. Average message dissemination delay versus number of service channels in WSD and the proposed CMD scheme.

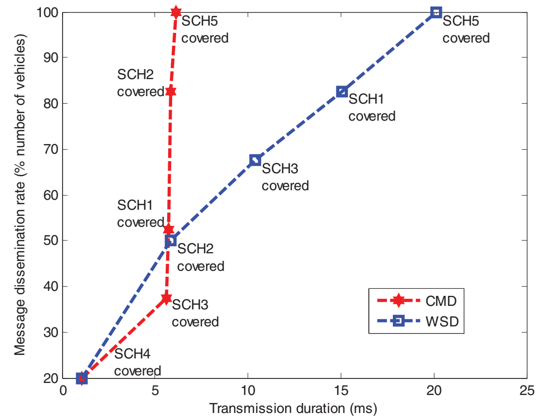

Fig. 3. Message dissemination rate versus transmission time in WSD and the proposed CMD scheme.

complete set of participating vehicles on the road.

Algorithm 1 elaborates on the CMD channel coordinator selection procedure. The following notations are relevant to understand Algorithm 1: S_d represents a vehicle to vehicle separation distance, R_{SCH} represents the service channel received in periodic message, N_{SCH} represents the number of service channels used to compute the LAD.

Algorithm 1: CHANNEL COORDINATOR SELECTION ALGORITHM

1. **while** in CCHI all vehicles advertise and gather location information
2. Select SCH to be tuned to
3. Append selected SCH to all safety messages and broadcast
4. **while** periodic safety messages are received
4.a **for** each vehicle
4.b For each R_{SCH} Compute the S_d 's each
4.c Compute the local LAD of the closest S_d 's each announcing a different R_{SCH}
4.d Append the local LAD to the periodic safety message and the N_{SCH} then broadcast the message
4.e **if** (broadcast is received and the selected SCH of the receiving vehicles is same as the one in the received safety message) **then**
4.f **if** (local N_{SCH} is greater than the all received N_{SCH} 's) **then**
4.g Vehicle is a channel coordinator
4.h **else if** (local N_{SCH} is equal to the received N_{SCH})
4.i **then**
4.j **if**(the received LAD values are greater than the local LAD values) **then**
4.k Vehicle is a channel coordinator
4.l **else**
4.m Vehicle is just a member of its selected SCH cluster.
4.n **End if**
4.o **else**
4.p Vehicle is just a member of its selected SCH cluster.
4.q **end if**
4.r **end if**
4.s **end for**
4.t **end while**
5. **end while**

IV. SIMULATION SETUP, ANALYSIS, AND DISCUSSIONS

To analyze the performance of CMD the proposed algorithm is evaluated in the NS-3 simulator [9], version ns-3-dev. The mobility traces are generated by Bonnmotion-2.1.3 [10]. Table I summarizes the general simulation parameters. A playground of 500 by 500 meters has been used in a Manhattan grid and the inter-vehicle distance is random.

In this study, the dissemination rate is defined as the percentage number of the total vehicles which have received safety messages in a given period of time. Figs. 2 and 3 show that the CMD scheme is better than WSD in terms of average dissemination delay and dissemination rate. This is mainly visible when more than three service channels are active. With only one channel, there is no switching so the dissemination delay is uniform for all the schemes.

TABLE I. SIMULATION PARAMETERS

Description	Value
Message payload size L	200 bytes
Loss model	Two ray ground propagation
packet interval	100 ms
Data rate R	6 Mbps
Content window size-Min, max	15, 256
Slot time (σ)	16 μs
AIFSN	2
SIFS time	32 μs
Antenna height	1.5 m
Frequency	5.9 GHz
Tx and Rx gain	3 dB
Channel model	Constant Speed Propagation Delay
Number of vehicles	50
Vehicle speed	40 m/s
Vehicle mobility model	Manhattan-grid highway
Simulation time	350 s

In terms of average dissemination delay shown in Fig. 2, it is observed that both WSD and CMD show almost the same performance when only one or two service channels exist. This is obviously due to the single switching to the other service channel in both cases. However when the service channels are more than two, CMD is better than WSD primarily because CMD uses will use two channel coordinators each performing only a single chanel switch when they receive the broadcast information. WSD will perform multiple switch operations using a single channel coordinator which eventually brings in a delay worse than CMD. Again, due to the multicordinator approach exhibited the CMD scheme, the message dissemination rate shown in Fig. 3 is much better than that provided by WSD.

V. Conclusion

In this paper, a cooperative multi-channel message dissemination scheme has been proposed for WAVE communications with the goal of improving on the dissemination delay of emergency messages. Through simulation analysis, our cooperative participation method can greatly improve on the dissemination delay in WAVE multi-channel communications compared to WSD.

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