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Piggybacking assisted many-to-Many communication with efficient vehicle selection for improved performance in vehicular ad hoc networks

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ABSTRACT

Vehicular Ad-hoc NETworks (VANETs) have lately gained the interest of researchers due to their unique properties of high mobility and constantly changing network topology. As mentioned in IEEE 802.11p which is the standard for VANETs, CSMA is used as the channel access mechanism. However, CSMA causes high contention and leads to lower network performance in terms of packet delivery ratio and average end-to-end delay. Many-to-Many (M2M) communication is a technique which makes use of simultaneous transmission of packets by using Code Division Multiple Access (CDMA). Although M2M communication helps to improve the performance of VANETs, further improvements can be done to fully reap the benefits of M2M communication. In this paper, we suggest piggybacking of information along with M2M communication in a vehicular network scenario. This leads to dissemination of more information from a vehicle at a time, thereby increasing the average packet delivery ratio and average end-to-end delay. Our simulation results confirm that piggybacking along with M2M communication helps to improve network performance in terms of packet delivery ratio and end-to-end delay. We mathematically analyse average packet delivery ratio and average end-to-end delay of such a system by modelling the buffers at vehicles and RSUs as M/M/1 and M/D/1 queues, respectively. Our analytical results are verified by extensive simulations. In M2M communication, vehicles are chosen randomly to enter in a communication session. In this paper, we formulate an optimization problem for selection of vehicles which can enter in a communication session and also propose an efficient vehicle selection algorithm for the same. Our proposed algorithm not only improves the average packet delivery ratio and average end-to-end delay of the network but also significantly reduces the number of packets dropped in the network.

1. Introduction

Vehicular Ad-hoc NETwork (VANET) or vehicular network is a network where communication happens between moving vehicles which are considered as nodes. For establishing communication, every vehicle is equipped with wireless devices known as On-Board Units (OBUs). In such a network, exchange of information with the Internet is also necessary for execution of applications. For this purpose, static infrastructure units known as Road Side Units (RSUs) are placed on the roads in a particular manner. They act as gateways between the Internet and the network of vehicles [1].

In recent years, VANET has emerged as a booming research area due to the challenges placed by high mobility of vehicles. The various applications supported by VANETs range from safety applications, for e.g – collision warning, lane change warning etc, to non-safety applications, for e.g – video download, gaming, chatting etc. Information about safety applications is communicated through emergency messages and periodic state messages. Emergency messages are high priority messages which are generated on the occurrence of critical safety events such as, road accidents, collision warning etc. Periodic state messages inform about the current state of a vehicle which include its current position, speed, and direction of movement. These messages are generated periodically. Information about non-safety applications is transmitted via infotainment messages. Since emergency, periodic, and infotainment messages support applications of VANETs, they are imposed with strict delay constraints. All these messages are transmitted over Dedicated Short Range Communication (DSRC) Spectrum which has one control channel and six service channels [1]. Emergency and periodic state messages are transmitted over the Control CHannel (CCH) and infotainment messages are transmitted

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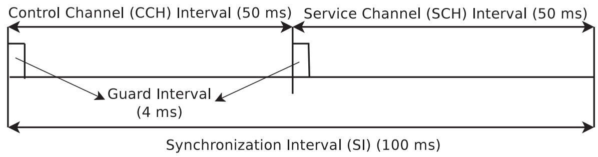

Fig. 1. IEEE 802.11p channel switching [12].

over the Service CHannels (SCHs). A transceiver has to switch alternately between CCH and SCH in a 100 ms long Synchronization Interval (SI), as shown in Fig. 1. Any technique can be considered to improve the performance of VANETs only if it improves the performance of all the various types of messages in VANETs.

It has been mentioned in the literature [1,2] that high mobility and constantly changing vehicle density are characteristics of VANETs which negatively impact and pose challenges in meeting the delay constraints of VANET applications. Also, to have an updated network it is necessary that the average Packet Delivery Ratio (PDR) is high. PDR is defined as the ratio of the number of packets successfully delivered to the total number of packets generated in the network. In high vehicle densities the challenge of achieving high PDR and low delay is enhanced due to contention. Contention arises due to – a) struggle between messages in the buffer of a vehicle so that they are chosen for transmission and, b) struggle between vehicles in order to acquire the channel to transmit their information [3,4]. IEEE 802.11p is the standard used for VANET applications. It follows IEEE 802.11e Enhanced Distributed Channel Access (EDCA) for prioritizing messages for transmission. Thus, messages in the buffer of a vehicle contend with each other, in order to get chosen for transmission. IEEE 802.11p uses Carrier Sense Multiple Access (CSMA) as the channel access mechanism [5,6]. In high vehicle density scenarios, use of CSMA leads to poor network performance [4]. This is because, CSMA enforces one-to-one communication scheme which allows only one pair of vehicles to communicate at any instant of time [3]. However, in general, in a VANET scenario, vehicles broadcast their information to the other vehicles/RSU in its transmission range. Also, with high vehicle density, contention to access the channel increases. A number of studies that overcome the drawbacks of CSMA are reported in the literature [7–11]. Hence, there is a need for an efficient message dissemination technique such that the drawbacks of CSMA are overcome and high PDR and low end-to-end delay are achieved.

In [12], we have proposed an M2M communication framework which helps in achieving the aforementioned requirements. M2M communication enables multiple vehicles to form a group and simultaneously transmit information among themselves. Simultaneous communication leads to reduced channel access delay and hence leads to improvement in average PDR and average end-to-end delay in the network. However, there is scope for further improvement in PDR and end-to-end delay. Piggybacking is a technique which refers to relaying the information of a few other vehicles along with a vehicle's own information [13]. We believe that using piggybacking of information along with M2M communication will further increase the performance of the network. Also, in M2M communication, vehicles are chosen randomly to enter in a communication session. Hence, there is no guarantee that all vehicles will get a chance to enter in any of the communication sessions. Vehicles which are unable to enter in a given communication session will not be able to send their data at that time. They wait to be chosen in the subsequent communication sessions. This may lead to high packet drops and high delay. This is because, a packet remains in the buffer of a vehicle until it gets a chance to transmit and if a packet is not transmitted before its delay bound is reached then the packet will be dropped and delay will also increase. Using an efficient way to select vehicles which can enter in a communication session will help in improving the PDR and end-to-end delay of the network.

In this paper, we propose the use of piggybacking of information in a VANET where M2M communication is used for transmission of messages. Piggybacking improves the average PDR and average end-to-end to delay of a VANET scenario for all types of messages (emergency, periodic, and infotainment). We have performed mathematical analysis to calculate average PDR and average end-to-end delay when piggybacking of information is used along with M2M communication. We have performed the analysis by modelling the buffers at vehicles and RSUs as M/M/1 and M/D/1 queues, respectively. Our analytical results are verified using extensive simulations. We have also formulated an optimization problem for efficient way of selection of vehicles which can enter in a communication session. We have proposed an Efficient Vehicle Selection (EVS) algorithm to select vehicles which can enter in a communication session. The EVS algorithm ensures that vehicles do not have to wait for long to enter in a communication session and guarantees lower delay and packet drops. It also helps in improving the average PDR.

2. Related work

In the recent years, vehicular networks have gained a lot of interest from researchers due to the wide range of applications it can provide as well as the challenges which are faced in their execution. All the applications in VANETs require their corresponding messages to have stringent delay constraints. As mentioned in IEEE 802.11p which is the standard for VANETs, CSMA is used as the channel access mechanism [6]. Use of CSMA leads to poor network performance due to high contention [4]. This is because in a VANET scenario, CSMA enforces only one pair of vehicles to communicate at a time.

In [7], the authors propose a medium access control protocol design where each packet is broadcast multiple times within its life time. The proposed method is designed for transmission of safety messages. Although the proposed protocol enhances the packet reception performance, but repeated rebroadcasting may lead to network congestion. In [8], Kaul et. al propose an application layer broadcast rate adaptation algorithm to achieve minimum delay. However, with increase in number of vehicles in the scenario, the delay increases. The authors in [14] propose a context-aware MAC protocol where improvement in network performance is brought by assigning priorities to vehicles which are contending for channel. However, in this technique too, only one communication takes place at a time. The authors in [10] propose a multichannel operation to improve the MAC protocol used in VANETs. This work focusses on efficient dissemination of safety related information. As a different approach to solve the problems posed by CSMA, dynamic adjustment of transmit power at PHY layer is proposed in [9]. This technique is proposed for transmission of safety related information. Although this technique lowers the end-to-end delay but dynamic estimation of channel conditions remains a challenge in a constantly changing network topology like VANETs. In [11], Kaul et. al propose a slotted transmission mechanism for disseminating periodic state messages. However, assigning time slots to different vehicles in a constantly changing network topology is a big challenge.

It has been mentioned by authors in [15] and [16] that VANETs can be considered as a subclass of Mobile Ad hoc NETworks (MANETs). VANETs differ from MANETs only due to their additional features such as, high mobility and constantly changing network topology. In [17], the authors show that use of Many-to-Many (M2M) communication in a MANET scenario improves the capacity of the network. This is because M2M communication enables multiple devices in a group to simultaneously communicate among