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

Moumita Patra*, C. Siva Ram Murthy

Department of Computer Science and Engineering, Indian Institute of Technology Madras, 600036, India

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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

* Corresponding author.
E-mail addresses: moumita@cse.iitm.ac.in, patramoumita88@gmail.com (M. Patra), murthy@iitm.ac.in (C. Siva Ram Murthy).

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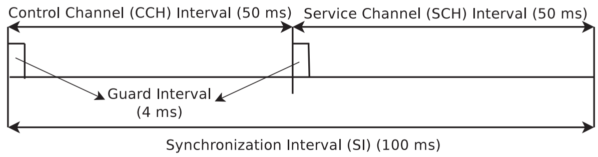

Fig. 1. IEEE 802.11p channel switching [12].

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 themselves for a given communication duration. This is enabled by using Code Division Multiple Access (CDMA) and also with the help of location services such as Global Positioning System (GPS) on a single IC chip [18,19]. In our work in [12], we have proposed that using M2M communication in a VANET scenario improves the average PDR and average end-to-end delay. However, there is still scope to improve the performance by sending more information at a time from a vehicle and by intelligent selection of vehicles which can enter in a communication session.

In this paper, we propose the use of piggybacking of information as an information dissemination technique along with M2M communication in a VANET scenario. This leads to transmission of a number of messages from a single vehicle at a time. This increases the average PDR and decreases the average end-to-end delay. Our simulation results confirm that piggybacking of information along with M2M communication helps to improve the average PDR and average end-to-end delay of a VANET. We also analyse the average PDR 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. The analytical results are in good agreement with the simulation results. For a further enhancement in performance, we formulate an optimization problem for selecting vehicles which can enter in communication session and propose an efficient vehicle selection algorithm. Our proposed algorithm not only improves the average PDR and average end-to-end delay but also reduces the number of packets dropped in the network.

The rest of the paper is organized as follows. Section 3 describes the settings of the network scenario along with the description about the routing scheme and the mobility model. We have described the M2M protocol in Section 3.1. The impact of piggybacking of information on the average PDR and average end-to-end delay with detailed mathematical analysis is presented in Section 4. The corresponding simulation results are also mentioned in Section 4. We have formulated an optimization problem for finding an efficient way of selection of vehicles and have proposed efficient vehicle selection algorithm in Section 5 along with the corresponding simulation results. Section 6 concludes the work and presents future work.

3. System model

Our system model consists of a two-dimensional city scenario with multiple lanes and intersections. Each road is divided into cells/sections of length l. An RSU is placed in the middle of a cell and is also capable of M2M communication. It has been shown in [20] that a transmission occurring at a distance greater than 2.2 $\times$ transmission range will not cause any interference to the ongoing transmission. We assume that RSUs are placed on the road in an optimal manner such that they do not interfere with each other during downlink transmission. This is done by placing RSUs after every 4 hops where one hop is the same as the transmission range of an RSU. This eliminates any interference between RSUs during downlink transmission. Vehicles are equipped with devices which enable M2M communication. GPS on the vehicle enables them to discover which cell they are in and also helps them to synchronize their communication.

3.1. M2M protocol

Many-to-Many communication allows several vehicles to transmit concurrently to many other neighbouring vehicles. It allows multiple transmitters to simultaneously transmit their information and also receivers to receive information from multiple transmitters. All the transmissions in M2M communication are decoded. This is done by using Code Division Multiple Access (CDMA). Each cell in the scenario is assigned a set of codes depending on the number of channels and the decoding hardware capability, as shown in Fig. 2. It is assumed that whenever a vehicle has to transmit its information it is assigned a code by a centralized server (oracle) which considers the vehicle's location for assignment of the code [17,19]. It is assumed that the centralized server has instantaneous information about the network and assigns codes to vehicles while allowing code reuse and mitigating the adverse effects of interference in each cell. Communication in such a scenario happens along half-duplex links and multiuser detection is used at the receiver to decode packets.

In our scenario we have assumed that M2M communication happens in a VANET scenario as shown in Fig. 3. Cells in which RSU is not present, M2M communication takes place among vehicles. Cells in which RSUs are present, communication takes place between vehicles as well as between vehicles and RSUs. This is because, RSUs act as gateways to the Internet for the ad-hoc network of moving vehicles. Hence, it is most important to send and receive messages from RSUs. Finally, RSUs broadcast information to all of the vehicles in their transmission range.

3.1.1. Channel assignment and channel access

In our scenario, we assume that vehicles are aware of their current location (current cell) with the help of GPS. GPS also helps in time synchronization among the vehicles which also ensures that communication in all the cells are synchronized. If a vehicle has data in its buffer and it is able to access the channel then it can start transmission.

For a given VANET scenario, realization of M2M communication (channel access) happens in each cell in the form of synchronized "communication sessions" (each of duration τ) comprising of two phases [3]. In the first phase, called the *setup* phase, vehicles discover their neighbours and then a random group of vehicles is chosen for communication. There is an upper limit α on the size of the group chosen. The value of α depends on the decoding hardware capability. If there are less than α vehicles in the cell then vehicles will be chosen for communication with high probability. Else, the scheme effectively chooses a random α-sized subset of the vehicles present in the cell for communication. In the second phase, called the *communication phase*, each vehicle in the set of size α is assigned a code out of the set of codes assigned to the corresponding cell. This is done by the centralized server. Once this is done, all the α vehicles can communicate with every other vehicle in that set.

3.2. Routing and scheduling scheme

A packet/message remains stored in a vehicle's buffer until the vehicle enters in a communication session and transmits the packet to other vehicles and RSU (if present in the proximity). A packet is considered to be successfully delivered only if it reaches an RSU and is consequently broadcast to vehicles in the RSU's transmission range. Messages are transmitted from the buffer of a vehicle or RSU in First-In-First-Out (FIFO) manner. Two ray path loss model is used for signal propagation.

3.3. Mobility model

We consider that vehicles in the system are distributed uniformly and the total number of vehicles in the system is fixed. However, the time after which vehicles change their speed follows exponential distribution [21]. Vehicles have bidirectional movement and vehicle density at intersections is comparatively higher than at the rest of the roads. We neglect the width of the road in comparison to its length and take the difference in the X-coordinate as a measure of separation between any two entities.

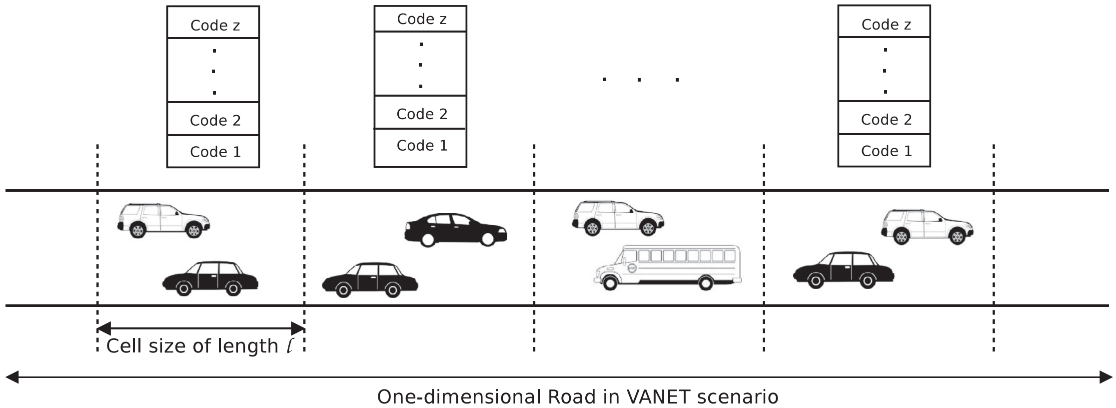

Fig. 2. Set of codes are assigned to each cell in the scenario.

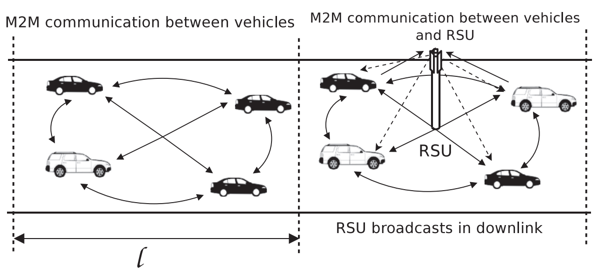

Fig. 3. Many-to-many communication [12].

4. Piggybacking of information

In this section we show the effect of piggybacking of information on various types of messages in a VANET scenario where M2M communication is used. Piggybacking of information for a vehicle refers to relaying the information of a few other vehicles along with its own information [13]. It facilitates dissemination of more information by a vehicle at a given time. In a network where M2M communication is used, piggybacking of information will further improve the average PDR and average end-to-end delay. Here, we first analyse the effect of piggybacking on the average PDR in a VANET scenario where M2M communication is used. Next, we show the effect of piggybacking on the average end-to-end delay in the same scenario.

4.1. Average packet delivery ratio

In [12], the authors have analysed the effect of M2M communication on the average PDR in a VANET scenario. We closely follow the analysis given in [12] and show the effect of piggybacking of information in the same scenario.

We assume that there are N vehicles in the scenario. Each road is divided into C cells and RSUs are placed after every k cells. α is the number of vehicles that can enter in a communication session and every vehicle can piggyback p packets including its own information. We assume that inter-arrival duration of packets at each vehicle follows an exponential distribution with rate λ_v. This is because, apart from periodically generated state messages, inter-arrival duration of all other messages (emergency and infotainment messages) generated in VANETs follow exponential distribution. Thus, we consider that the joint inter-arrival distribution of packets at vehicles follows exponential distribution. The number of packets generated at a given time instant is given by N/λ_v and the number of active communication sessions at a given time will be C/k.

With piggybacking, a vehicle transmits p packets at a time. Also, in M2M communication, apart from the RSU, a vehicle also transmits its information to all the other $\alpha-1$ vehicles which are in its communication session. Therefore, the number of packets replicated in a cell will be $\alpha(\alpha-1)p$. It should be noted that, we consider a packet to be successfully delivered only if it reaches an RSU from a vehicle and the RSU then broadcasts it to all the vehicles in its transmission range. Considering the aforementioned assumption, successful transmissions will happen only in cells containing an RSU. Therefore, in this scenario, the total number of active communication sessions at a given time instant will be C/k. In all the C/k cells, α vehicles will be transmitting p packets to the RSU in their transmission range. Therefore, the total number of successful transmissions at a given time instant will be given by $S=\alpha pC/k$. The number of packets remaining in all the vehicles in the network, R, is given by

$$R=\frac{N}{\lambda_v}-\frac{\alpha pC}{k}+\frac{\alpha(\alpha-1)pC}{k} \quad (1)$$

After t communication sessions, the total number of packets generated, T, will be the sum of the total number of packets successfully transmitted and the total number of remaining packets.

$$T=Rt+St=\left(\frac{N}{\lambda_v}+\frac{\alpha(\alpha-1)pC}{k}\right)t \quad (2)$$

The average PDR is the ratio of the total number of packets successfully delivered to the total number of packets generated in the network. In this case, the average PDR, Φ, is given by

$$\Phi=\frac{\alpha\ pC}{k\left(\frac{N}{\lambda_v}+\frac{\alpha(\alpha-1)pC}{k}\right)} \quad (3)$$

Thus, we can see that in the presence of piggybacking, the average PDR will increase. We have performed simulations to validate our analysis. The simulations have been carried out on a one-dimensional (1D) road where M2M communication is used and vehicles piggyback information of other vehicles. The variation of average PDR with different number of vehicles has been shown in Fig. 4 for both the analysis and simulation. It can be seen that the analytical results closely follow the simulation results.

4.2. Average end-to-end delay

The average end-to-end delay is defined as the total amount of time a packet has to wait until it gets successfully delivered to a vehicle. As mentioned in Section 4.1, a packet is said to be successfully delivered if it reaches an RSU via transmission and is subsequently broadcast to other vehicles in its transmission range.

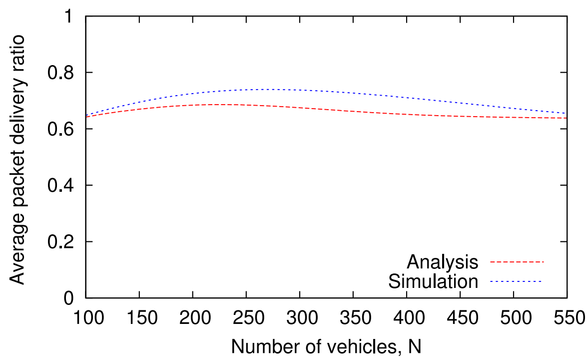

Fig. 4. Analysis vs. simulation for average PDR with piggybacking of information for $\alpha = 4$ and $p = 6$.

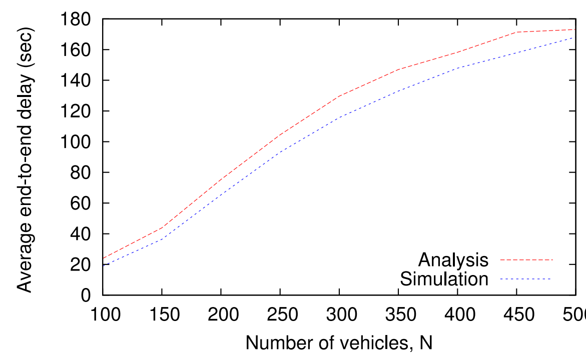

Fig. 5. Analysis vs. simulation for average end-to-end delay with piggybacking of information.

Therefore, for the analysis of end-to-end delay of a packet, we consider a 1D road with RSUs placed in the same way as mentioned in Section 3. In M2M communication, a packet remains in a vehicle's (RSU's) buffer until the vehicle (RSU) enters in a communication session and if that particular packet is chosen for transmission. Also, for M2M communication, α vehicles are chosen randomly from the transmission range of the RSU. Thus, for a vehicle, the duration between two successive transmissions is independent of each other. We assume the service rate of packets from a vehicle to follow exponential distribution with mean μ_v^p. It should be noted that, on introducing piggybacking of information, more number of packets will be transmitted from a vehicle at a time as compared to an M2M communication scenario without piggybacking of information. Thus, if the service rate of a vehicle in an M2M communication scenario without piggybacking is μ_v and the service rate of a vehicle in an M2M communication scenario with piggybacking is μ_v^p, then $\mu_v^p > \mu_v$. Also, as mentioned in Section 4.1, the joint inter-arrival distribution of packets at vehicles is assumed to follow exponential distribution with mean λ_v. With the aforementioned conditions, the buffer of a vehicle can be modelled as an M/M/1 queue and the server utilization factor of a vehicle's buffer ρ_v will be given by λ_v/μ_v^p.

For transmission of packet from a vehicle's buffer to an RSU, the expected waiting time, $E[W_v]$, is given by

$$E[W_v] = \frac{\rho_v}{\mu_v^p(1-\rho_v)} \tag{4}$$

If size of each packet is assumed to be m, then with piggybacking of p packets, the transmission delay, t_v, will increase and is given by

$$t_v = \frac{mp}{b_v} \tag{5}$$

where, b_v is the bandwidth of each individual link in M2M communication between vehicles.

Once a packet reaches an RSU, it has to wait in its buffer until it reaches the head of the buffer and is chosen for communication. In the downlink, only RSUs broadcast information to the vehicles in their transmission range. Therefore, they do not face any contention in accessing the channel for transmission of packet(s). Due to absence of contention for accessing the channel, the waiting time for a packet in the RSU's buffer will only be dependent on the time it requires to reach the head of the buffer which is dependent on the average buffer size of the RSU. We have assumed that packets arrive at vehicles according to a Poisson process. In a cell, packets reach an RSU's buffer after they are transmitted from the vehicles which enter in communication session. Since the sum of independent Poisson processes is also Poisson, arrival rate of packets at an RSU is assumed to follow a Poisson process with mean λ_{RSU}. Considering the aforementioned conditions, the buffer at an RSU can be modelled as an M/D/1 queue. The service rate at the RSU's buffer is denoted by μ_{RSU}^p. Similar to the assumption for the uplink scenario, the service rate at an RSU (μ_{RSU}^p) where piggybacking of information is used is greater than the service rate in the scenario where piggybacking of information is not used (μ_{RSU}). The waiting time of a packet at the buffer of an RSU, $E[W_{RSU}]$, is given by

$$E[W_{RSU}] = \frac{\rho_{RSU}}{2\mu_{RSU}^p(1-\rho_{RSU})} \tag{6}$$

where

$$\rho_{RSU} = \frac{\lambda_{RSU}}{\mu_{RSU}^p} \tag{7}$$

The transmission delay of the piggybacked packets, t_d, is given by

$$t_d = \frac{mp}{b_R} \tag{8}$$

where b_R is the available bandwidth for downlink communication by RSU.

Thus, the average end-to-end to delay for a packet, $E[W]$, will be the sum of the delay terms obtained from Eqs. 4–6 and 8 and is given by

$$E[W] = E[W_v] + t_u + E[W_{RSU}] + t_d \tag{9}$$

We have performed simulations with same settings as mentioned in Section 4.1 to verify our analysis. Fig. 5 shows the variation in average end-to-end delay with number of vehicles when M2M communication and piggybacking of information are used in a VANET scenario. It can be seen that the trends of both analysis and simulation closely match.

4.3. Validation via simulations

In this section, we present results of simulations carried out in a VANET scenario where piggybacking of information is used along with M2M communication. Our simulation scenario consists of a two-dimensional city scenario with roads and intersections, as shown in Fig. 6. The scenario can be easily scaled to larger dimensions. Each road in the scenario is of length R and each road is divided into cells of length 600 meters. RSUs are placed uniformly. Vehicles are assumed to be distributed uniformly in the simulation region, keeping total vehicle count fixed during the entire simulation duration. All the OBUs are assumed to have equal transmit power. RSUs and OBUs are assumed to have equal transmission radius. In this work, our focus is on messages related to safety and non-safety applications. We refer to safety applications such as, uneven terrain gaze, sunshine right in front of eyes, a vehicle needs help because it broke down, ran out of gas or collided with an

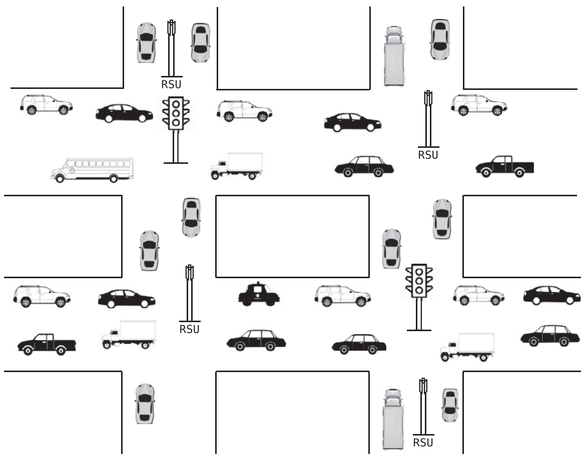

Fig. 6. System scenario.

Table 1
Simulation parameters.

Parameter	Value
Road length (*R*)	10 Km
Lanes (Bidirectional traffic)	2
Average vehicle speed	30 – 150 Km/Hr ≈ 8.33 – 41.66 m/sec
Transmission radius	300 m
Cell length (*l*)	600 m
Data rate	6 Mbps
α	4
τ	0.1 sec
Periodic & emergency message size	1 KB
Infotainment message size	32 KB

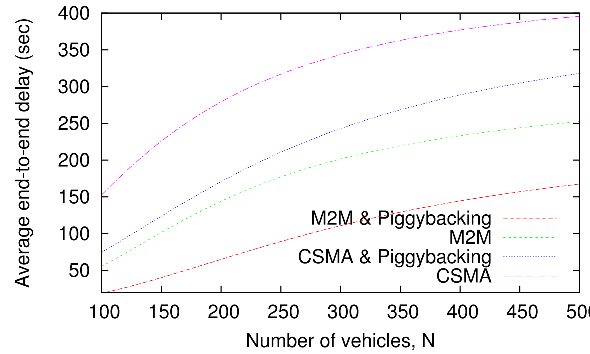

Fig. 7. Average end-to-end delay vs. N, periodic messages.

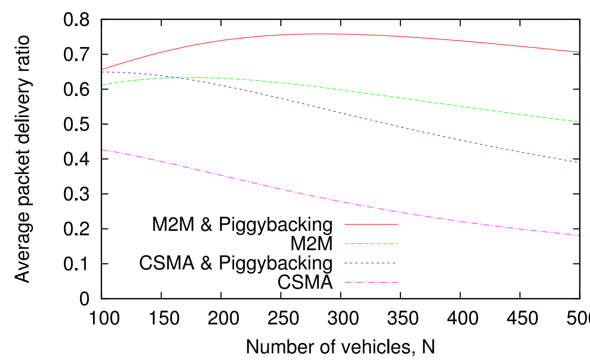

Fig. 8. Average PDR vs. N, periodic messages.

obstacle but poses no risk to anyone. With regard to non safety applications, we refer to applications such as, looking for nearby hotels or shopping malls and downloading a map. Messages corresponding to these applications are transmitted according to their priority. However, these messages are delay-tolerant and their focus is on relevant and correct information and not on up-to-date information.

We have used a discrete event simulator based on JAVA and the obtained results have been averaged over 1000 simulation runs with 95% confidence interval. The rest of the simulation parameters are shown in Table 1 [5,17,22].

We propose the use of piggybacking of information along with M2M communication in VANETs. In [12], M2M communication has been used in VANETs without piggybacking of information. Piggybacking in CSMA-based VANETs has already been suggested in [8]. Therefore, to manifest the strength of our proposed technique, we compare its performance with scenarios where – a) only M2M communication is used, b) CSMA is used as the channel access mechanism along with piggybacking of information, and c) only CSMA is used as the channel access mechanism without piggybacking of information. We have compared the results of the aforementioned techniques for different types of messages – periodic messages, emergency messages, and infotainment messages.

We first evaluate the performance of the aforementioned techniques with respect to periodic messages which are generated periodically after every 100 ms, i.e, one SI. The average speed of vehicles is considered to be 20 m/sec. Fig. 7 shows the variation in average end-to-end delay with number of vehicles for periodic messages. It can be observed that introducing piggybacking of information with M2M communication gives better performance when compared to scenarios where only M2M communication is used or CSMA is used (with and without piggybacking of information). This is because M2M communication facilitates simultaneous transmission of information but when piggybacking is added to it, more information can be transmitted at a time. However, in all the cases, delay increases with an increase in number of vehicles. This is because with increase in number of vehicles, contention among vehicles to access the channel or contention to enter in a communication session increases.

Fig. 8 shows the variation in average PDR with number of vehicles, for periodic messages. Here, M2M communication gives better performance with piggybacking of information as compared to all other techniques. This is because with piggybacking and M2M communication, more number of messages can be transmitted at a time leading to high PDR. It an be observed that for lower number of vehicles, *CSMA & Piggybacking* performs better than the scenario where only M2M communication is used. This is due to the reason that with lesser vehicles in the scenario, number of vehicles which can enter in a communication session is also low. However, with piggybacking in CSMA, more information can be transmitted at a time even with lesser number of vehicles. It should be noted that for all the techniques, PDR decreases with increase in number of vehicles due to contention.

Figs. 9 and 10 represent the variation in average end-to-end delay and average PDR with number of vehicles for emergency messages. The average vehicle speed here is 20 m/sec. It can be observed from Fig. 9 that *M2M & Piggybacking* gives lower average end-to-end delay due to transmission of more packets at a time. However, with an increase in number of vehicles, delay also increases due to contention. For the techniques – *M2M* and *CSMA & Piggybacking*, it can be noted that the delay is approximately equal for lower values of N. This is because for lower N, in case of *M2M*, there are a few vehicles which can enter in communication session whereas in case of *CSMA & Piggybacking*, more information can be transmitted at a time. This leads to lower delay.

We now discuss the behaviour of infotainment messages for the aforementioned techniques. Figs. 11 and 12 represent the variation

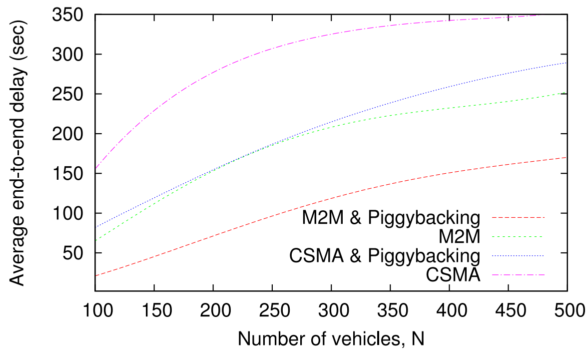

Fig. 9. Average end-to-end delay vs. N, emergency messages.

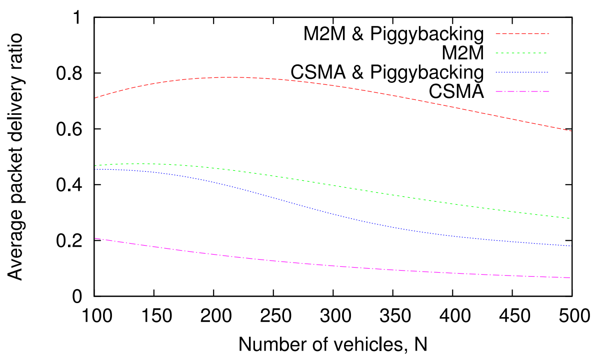

Fig. 10. Average PDR vs. N, emergency messages.

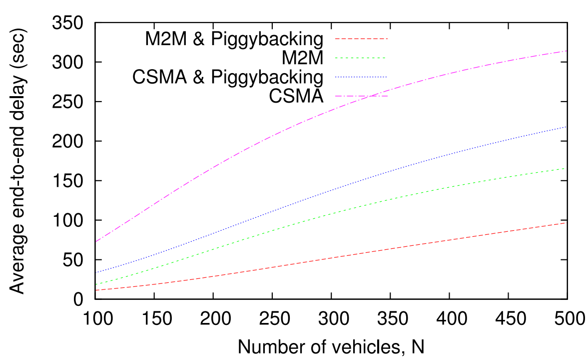

Fig. 11. Average end-to-end delay vs. N, infotainment messages.

in average end-to-end delay and average PDR with number of vehicles (average vehicle speed – 20 m/sec). As has been seen for periodic and emergency messages, here too, M2M communication with piggybacking of information performs better than scenarios *M2M, CSMA & Piggybacking*, and *CSMA*. However, average PDR for *CSMA & Piggybacking* is better than *M2M* and *M2M & Piggybacking* for lower number of vehicles, as shown in Fig. 12. This is because, with lower number of vehicles, vehicles entering in communication decreases leading to higher delay. However, once there are enough vehicles in the network such that all the communication sessions have the required number of vehicles, the PDRs in case of *M2M* and *M2M & Piggybacking* improve.

5. Selection of vehicles

As mentioned in Section 1, performance of VANETs using M2M communication can be improved by introducing piggybacking of information and by efficient selection of vehicles for M2M communication. In Section 4 we have shown how piggybacking helps in improving average end-to-end delay and average PDR of a VANET

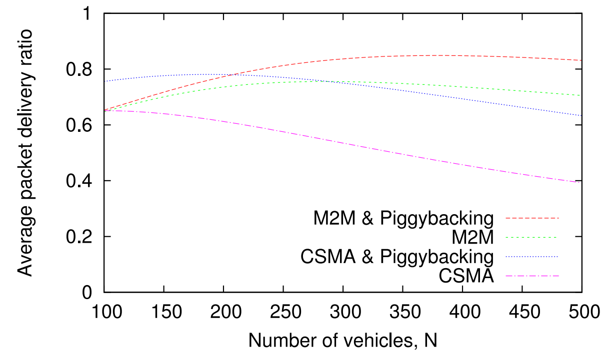

Fig. 12. Average PDR vs. N, infotainment messages.

scenario. In this section, we focus on efficient selection of vehicles for entering in communication session, in a cell. We formulate an optimization problem for finding the vehicles which should enter in a communication session. We know from Section 3.1 that in a cell, α vehicles are chosen randomly which enter in a communication session and start transmitting information to each other. This may lead to high packet drops and high delay as random selection of vehicles does not guarantee that all vehicles get a chance to enter in any communication session. Thus, an intelligent way of selection will help to reduce delay and increase PDR. Our aim is to a) decrease the average end-to-end delay and b) increase the average PDR of the network. Hence, our objectives can be represented as

$$min \sum_{i=0}^{N} \mathbb{I}_i.E[W_i] \quad (10)$$

$$max \sum_{j=0}^{C} x_j$$

Here, $E[W_i]$ represents the delay incurred by packets in the i^{th} vehicle and $\mathbb{I}$ is an indicator variable which represents whether the i^{th} vehicle is selected for entering in a communication session. $\mathbb{I}$ is given by

$$\mathbb{I}_i = \begin{cases} 1 & \text{if vehicle } i \text{ is selected for communication} \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

x_j represents the PDR in cell j. The given objectives are subject to certain constraints which are described below:

$$\sum_{i=0}^{N} \mathbb{I}_i \leq \alpha.C \quad (12)$$

$$E[W_i] < W_{max} \qquad \forall i = 1, \cdots, N \quad (13)$$

$$x_j > \delta \qquad \forall j = 1, \cdots, C \quad (14)$$

Eq. 13 constraints the number of vehicles entering in a communication session in each cell to α. W_{max} is the maximum delay bound and Eq. 14 represents that the average end-to-end delay for each vehicle is below W_{max}. The last equation constraints the PDR in each cell (x_j) to be above a threshold value δ. Due to the presence of multiple objectives and the combinatorial nature of the problem, a multi-criteria knapsack problem can be reduced to the given problem in polynomial steps. Since multi-criteria knapsack problem is NP-hard [23], the given problem is also NP-hard. Hence, we propose a heuristic to select the vehicles which should enter in communication session.

We use the benefits of piggybacking of information along with the delay incurred by packets at the head of the buffer of each vehicle to select those vehicles which should enter in communication session.

Algorithm 1 EVS algorithm

1: **Input:**
2: N : List of vehicles in the network.
3: C: List of cells in the network.
4: V: Set of vehicles in a cell c, $c \in C$.
5: S: Set of vehicles in a communication session in a cell c, $c \in C$.
6: v: Any vehicle in the network.
7: t: Time left to reach W_{max} for a packet.
8: B: Buffer size of a vehicle.
9: p: Number of packets that can be piggybacked.
10: **Output:**
11: Set of vehicles in each cell which can enter in a communication session.
12:
13: **for all** $c \in C$ **do**
14:     **for all** $v \in V$ **do**
15:         **if** $(B \geq p) \wedge (t < W_{max})$ **then**
16:             $A \leftarrow v$
17:         **end if**
18:     **end for**
19:     Sort_by_t(A)
20:     **while** (α nodes are chosen) $\vee$ (A is empty) **do**
21:         $S \leftarrow v$
22:     **end while**
23: **end for**

5.1. EVS Algorithm

In this sub section, we describe our proposed efficient vehicle selection algorithm. We consider that each packet at the head of the buffer of a vehicle has a time stamp which determines the amount of time left before it has to be dropped (or W_{max} is reached). The EVS algorithm is implemented in each cell by a centralised server which is assumed to have the information of all the vehicles in the given scenario. The EVS algorithm ensures that vehicles do not have to wait for long and guarantees lower delay and packet drops. The EVS algorithm states that vehicles whose packets at the head of the buffer are close to the delay bound are chosen for transmission. This will help in choosing those vehicles which are waiting to enter in a communication session, thereby ensuring that currently out-of-session vehicles will have their chance to transmit information in the upcoming communication sessions. Algorithm 1 is the EVS algorithm and it helps to determine the vehicles which should enter in a communication session.

In Algorithm 1, the objective is to select a set of vehicles in each cell which can enter in a communication session such that, the average PDR and average end-to-end delay are improved. Since piggybacking will help to increase the average PDR, the algorithm focusses on first selecting those vehicles in a cell which have at least p packets in their buffers. This is done to ensure piggybacking of packets in each transmission. To ensure lesser packet drops and average end-to-end delay, those vehicles whose packets will reach W_{max} soon, are chosen. In steps 13–17, a set of vehicles in each cell are chosen and kept in a temporary set A. All the vehicles in A have at least p packets in their buffers and their t value has not reached W_{max}. Here, t is the time left to reach W_{max} for a packet at the head of the buffer of a vehicle v. For each cell c, A is then sorted in increasing order as per the t values of each vehicle as shown in step 19. Finally, α vehicles are selected for each cell which can enter in a communication session, as shown in steps 20–22.

5.1.1. Simulation results

We have performed simulations on the scenario mentioned in Section 4.3 with our proposed algorithm. The obtained results corroborate the fact that using an efficient way of selecting vehicles which can enter in a communication session will result in better network performance. We use Packet Drop Ratio (PDrR) as a metric to evaluate the performance of the network, apart from the already mentioned metrics – average end-to-end delay and average PDR. PDrR is defined as the ratio of the number of packets dropped to the total number of the packets generated in the network ($PDrR = 1 - PDR$). A packet is dropped if it is not successfully delivered before W_{max} time. We use the proposed EVS algorithm in a VANET scenario where M2M communication is used along with piggybacking of information. We compare the performance of the EVS algorithm with the VANET scenario where M2M communication with piggybacking of information is used and vehicles are selected randomly for entering in a communication session. Random selection is the only vehicle selection technique mentioned in the literature for M2M communication. Thus, comparison of our proposed algorithm with random selection is justified.

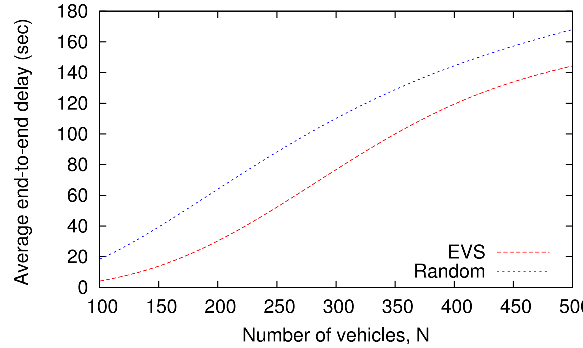

Fig. 13. Average end-to-end delay vs. N.

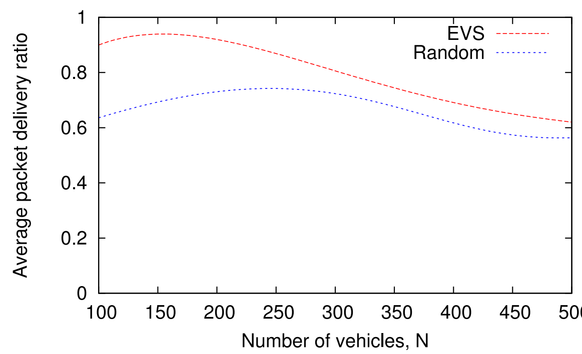

Fig. 14. Average PDR vs. N.

Fig. 13 shows the variation in average end-to-end delay with N when vehicles are selected using – EVS algorithm and random selection. It can be observed that EVS algorithm gives better delay performance than random selection of vehicles. This is due to the reason that selecting vehicles according to delay incurred by packets leads to lower overall delay. Also, choosing vehicles which have packets to piggyback, enforces the fact that more number of packets are transmitted at a time, leading to further decrease in delay.

The comparison of average PDR with number of vehicles for EVS algorithm and random selection of vehicles is shown in Fig. 14. In both cases the PDR decreases with an increase in number of vehicles but EVS algorithm performs better than random selection of vehicles throughout.

The variation in average PDrR with varying number of vehicles is shown in Fig. 15. In this case, selecting vehicles as per the delay incurred by packets at the head of their buffers leads to lesser number of packets reaching their delay bound. This results in lower drop ratio. Thus, EVS algorithm performs better than random selection of vehicles. However, as the number of vehicles in-

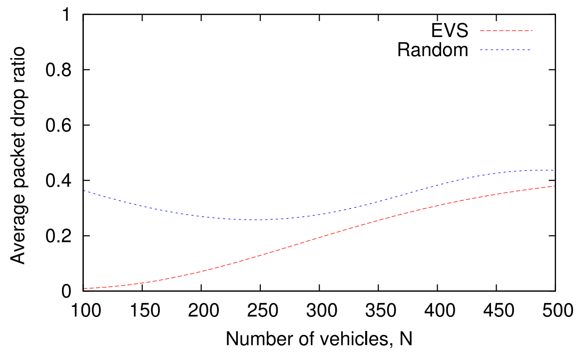

Fig. 15. Average PDrR vs. N.

creases, the number of packets dropped also increases due to contention.

6. Conclusion and future work

In this paper, we have shown that many to many communication when aided by piggybacking of information in a VANET, gives better performance in terms of average packet delivery ratio and average end-to-end delay. This is because, piggybacking leads to dissemination of more messages from a vehicle at a time. We have analysed the average packet delivery ratio and average end-to-end delay of such a scenario by modelling the buffers at vehicles and RSUs as M/M/1 and M/D/1 queues, respectively. Our analytical results are validated by extensive simulations. We have formulated an optimization problem which depicts the way in which vehicles should be selected to enter in a communication session. To further enhance the performance, we have proposed an efficient vehicle selection algorithm which improves the average packet delivery ratio and average end-to-end delay. Additionally, our proposed algorithm also reduces the number of packets dropped. Future work in this direction includes developing a technique to assign codes to different vehicles in a distributed manner.

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Moumita Patra is currently a PhD student in the High Performance Computing and Networking Lab at Indian Institute of Technology Madras, India. She received the Bachelors degree (B.Tech) in Computer Science and Engineering from West Bengal University of Technology, West Bengal, India and Masters degree (M.Tech) in Computer Science and Engineering from Hyderabad Central University, Telangana, India. Her research interests include delay performance improvement and efficient information dissemination techniques in vehicular ad hoc networks.

C.Siva Ram Murthy earned his B.Tech. degree in Electronics and Communication Engineering from Regional Engineering College (now National Institute of Technology), Warangal in 1982, M.Tech. degree in Computer Engineering from the Indian Institute of Technology (IIT), Kharagpur in 1984, and Ph.D. degree in Computer Science from the Indian Institute of Science, Bangalore in 1988. Since September 1988, he has been with the Department of Computer Science and Engineering at IIT Madras where he is currently a Professor. He has served as Head (Chairman) of the Department from 2010 to 2013 and held the Indian National Academy of Engineering (INAE) Chair Professorship during 2012-14. He is a co-author of the textbooks Parallel Computers: Architecture and Programming (Prentice-Hall of India, India), New Parallel Algorithms for Direct Solution of Linear Equations (John Wiley & Sons, Inc., USA), Resource Management in Real-time Systems and Networks (MIT Press, USA), WDM Optical Networks: Concepts, Design, and Algorithms (Prentice Hall, USA), An Analytical Approach to Optical Burst Switched Networks (Springer, USA), and Ad Hoc Wireless Networks: Architectures and Protocols (Prentice Hall, USA). His research interests include wireless networks, lightwave networks, real-time systems, and parallel and distributed computing. Dr.Murthy is a co-recipient of Best Paper Awards from the 5th IEEE International Workshop on Parallel and Distributed Real-Time Systems (WPDRTS), 6th and also 11th IEEE Annual International Conference on High Performance Computing (HiPC), and 14th and also 19th IEEE International Conference on Networks (ICON). He has served as an Associate Editor of the IEEE Transactions on Computers and as a Subject Area Editor for the Journal of Parallel and Distributed Computing (JPDC). He is currently an Associate Editor of the IEEE Transactions on Mobile Computing. He is a recipient of Best Ph.D. Thesis Award from the Indian Institute of Science, INSA Medal for Young Scientists, Dr. Vikram Sarabhai Research Award, IBM (USA) Real-Time Innovation Award, and Erasmus Mundus Academic Staff Scholarship. He is an elected Fellow of Institute of Electrical and Electronics Engineers (IEEE, USA), Indian National Science Academy (INSA) and Indian National Academy of Engineering (INAE).