A Distributed Cluster Based Transmission Scheduling in VANET

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Abstract— In this paper, we propose methods to enable efficient data delivery in vehicular ad-hoc networks (VANETs). We target scenarios where data are collected by vehicles and need to be transmitted. Dynamic clusters are formed while vehicles move in order to make data transmissions more robust and scalable. We use mathematical optimization solutions to optimize transmission scheduling so as to maximize throughput and minimize delay in delivering data. This paper defines an optimization model which addresses the max-min flow allocation problem by decomposing it into a master problem and a sub-problem. Our proposed scheme implements a contention free based medium access control where physical conditions of channel have been fully analyzed. Extensive simulations were performed for different scenarios to show the performance of the proposed Distributed Cluster Based (DCB) transmission scheduling scheme.

Keywords— contention-free; optimization; transmission scheduling; VANET; CSMA/CA

I. INTRODUCTION

Nowadays, vehicles integrate computers and data processing units as standard. Vehicles also constitute the central elements for processing data from available on-board sensors. Vehicular technology has been investigated to make vehicles intelligent, have more pleasant driving experience, achieve accidents mitigation, and an easier road traffic management. Enclosed in the vehicular technology, is vehicular communication which leverages wireless communication devices to make vehicles interact with their environment. To support vehicular communication operations, the US Federal Communications Commission (FCC) has allocated 75 MHz spectrum in the 5.9 GHz band for Dedicated Short Range Communication (DSRC).

The intelligent transportation society of America suggested the adoption of a single standard for physical (PHY) and medium access control (MAC) layers of architecture and suggested one advanced standard based on 802.11 (called 80211p). The channel access mechanism in 802.11p is based on enhanced distributed channel access (EDCA) which was adopted in IEEE 802.11e standard. It includes back-off which consists of using fixed and random waiting times to access the channel. The fixed waiting time is the number of slots given by the parameter arbitration inter-frame spacing (AIFS) number. The random waiting time is the number of slots derived from contention window (CW). The CW initial size is given by factor CWmin. When a transmission fails, the CW size will be doubled till reaching the maximum size given by the parameter CWmax. In random access MAC protocols (CSMA\CA), nodes contend in the communication medium to transmit data. Hence, data collisions, namely access interference, are possible. Interference occurs because there are multiple active transmission links in a network. Interferences affects the capacity of links. In the presence of interference, there are packet drops and sometimes interferences may lead to deactivation of communication links.

In the context of traffic engineering in VANET, the notation of traffic matrix modelling is not well defined for the vehicular environment as the sets of vehicles are highly dynamic and their traffic capacities are almost impossible to be known. Therefore traffic matrices are almost unidentified.

We use mathematical optimization tools to have contention free transmission (CFT) scheduling mechanisms which improve vehicles data delivery in the clustered VANET. Here, we are interested in transmission scheduling within two-hop neighbourhood. For that, we first rely on dynamic clustering of vehicles, which provides the possibility to control resource sharing and management functions in VANETs. Many clustering algorithms have been proposed in previous works [1, 2]. To construct clusters, we use the multi-hop clustering algorithm proposed in [3], as it provides the option to have the desire sized clusters. Our optimization solution will decide on activating different sets of communication links for specific operation times in order to maximize data delivery and minimize delay of delivered data during the data delivery time. In our proposed scheme, cluster head (CH) is responsible to perform the transmission scheduling based on the physical knowledge of the network provided by its cluster members (CM).

Our contributions are as follows: 1) we propose a distributed cluster based (DCB) transmission scheduling in VANET which looks to provide CFT opportunities to transmitter nodes 2) we develop a non-compact mathematical optimization model to address our DCB scheduling by; first defining a binary integer programming (BIP) solution to find the different subsets of active links which can transmit simultaneously and, then a linear programming (LP) solution which tries to maximize the delivered traffic flow by assigning different time periods to the different subsets of active links 3) we show that our DCB

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transmission scheduling improves the network performances in terms of throughout and delay.

The rest of this paper is organized as follows. Section 2 describes related works. Section 3 presents notions. Section 4 discusses the optimization model. Section 5 describes the transmission planning. Section 6 evaluates the proposed scheme with simulations and section 7 concludes the paper.

II. RELATED WORKS

The MAC protocol designed for 802.11p, which is based on CSMA/CA can be impacted by several factors, such as vehicles high mobility, hidden node problem, and interference problem. In a dense network situation, most of vehicles probably will choose a long contention period to access the medium which, in turn, will decrease the packet delivery rate and increase the delay for delivering packets.

Several protocols were proposed to address the mentioned issues over the last few years. For example, space division multiple access (SDMA) protocol [4] which assigns different frequency bands to the multiple space units in the network. Another example is ADHOC MAC [5] where transmission scheduling is performed based on assigning time slots into different time periods to vehicles willing to access the medium. Nevertheless, the performance of these two protocols will be affected in high dense scenarios because of the contention and hidden terminal node problem which can be alleviated by clustering of vehicles.

In [6], the authors proposed to improve the MAC layer by clustering vehicles and allowing the CH to coordinate the CMs access to the shared medium. Their scheme incorporates the clustering algorithm, contention free and contention based MAC to support real time transmission of safety messages, non-real time V2V communication while satisfying the required quality of service. The algorithm uses vehicle movement direction as clustering metric and schedules transmissions in one-hop communication range.

D-CBM [7] is a scalable cluster based MAC protocol which solves the hidden terminal node by grouping vehicles which have the lowest relative mobility together in clusters. In their work, CH schedules transmissions and broadcasts the schedule in a one-hop cluster region. D-CBM can work either based on CSMA/CA or collision free time division multiple access (TDMA) schemes.

In [8], authors proposed a quality of service-based transmission scheduling called "QOS-TDMA" by using pre-reserved time slots which satisfy service priority. To perform on-hop scheduling, the authors use clustering based on the speeds and directions of vehicles. In the clusters, CH takes the role of coordinator and assigns the needed number of slots based on the required quality of the service.

TC-MAC [9] is another cluster based MAC scheme where CH assigns different time slots to its one-hop CMs in order to provide fairness and decrease interferences. The proposed MAC aims to achieve intra-cluster communication access without collisions in the network.

All the above schemes aim to mitigate transmission interferences in a one-hop area. In [10], a vehicular deterministic medium access control (VDA) was proposed. VDA scheme decreases the transmission delay and reduces the packet collisions by scheduling the transmission within two hop neighbourhoods. The scheduling happens in contention free period durations which are negotiated between vehicles in the same neighbourhood. In this work, we compare the results of our transmission scheduling scheme to VDA in terms of network throughput and packet delays.

III. NOTATIONS

In the following, the terms vehicle and node are used interchangeably. The VANET topology is modeled by a set of nodes $V, v \in V$ and the set of links E, $e \in E$. The originating node of link e, $a(e)$, is the transmitter and the terminating node of link e, $b(e)$, is the receiver node. $e = vw$, $v, w \in V$ represents a link between node v and w and $a(e) = v, b(e) = w$. We assume that if $vw \in E$, then link e'=wv will be opposite of link vw. The set of links outgoing from and incoming to node v are denoted by $\delta^{+}(v)$and $\delta^{-}(v)$ respectively, and the set of all the links incident to node v is defined as $\delta(v) = \delta^{+}(v) \cup \delta^{-}(v)$.

We assume that p_{vw} is the transmitting power from node v to node w (we can also represent it in dBm scale with $\hat{p}_{vw}$). A communication link can transmit if it satisfies the signal to noise ratio (SNR) constraint [11]:

$$\text{SNR}: \frac{p_{vw}}{N} = \Gamma' \text{ , SNR} \geq \gamma \text{ ,} \tag{1}$$

Where γ is the SNR threshold and N is the noise power density.

In wireless networks, interference exists from various devices. For every link to be able to transmit, we define a new formula for signal to interference noise ratio (SINR) as follows:

$$\text{SINR}: \Gamma = \frac{p_{vw}}{N + \sum_{a \in A \backslash \{v\}} p_{aw}} = \frac{p_{vw}}{N + I_{vw}} \text{ ,} \tag{2}$$

Where A is a set of active nodes, $A \subseteq V$, and I_{vw} is the interference sum which is received from other transmitting nodes. For link vw to be active, we should have $\Gamma \geq \gamma$.

IV. OPTIMIZATION MODEL

In this section we model our DCB transmission scheduling in vehicular ad-hoc networks through mixed integer programming (MIP) and LP solutions. We define a common way of dealing with Max-Min flow allocation problem joined with VANET radio link modeling and a non-common way of dealing with traffic uncertainty. Moreover, column generation approach for the proposed MIP is presented [11].

We assume transmitters are contending for link capacities. When vehicles are in each other's vicinity, it would not be possible for all nodes to transmit simultaneously because of interferences. The scheduling of transmitting links should be optimized to address this issue. Consequently, we propose a solution on how to optimize the scheduling of the transmitting links in different time periods to maximize the data delivery and minimize the packet delay. In our optimization model, we accurately describe the transmission scheduling and our goal is to maximize the minimum flow by accurately scheduling the transmissions. The problem is formulated as MIP model with the concept of compatible set (CS). A CS is a set of links which can transmit (be active) concurrently within a tolerable interference. In the optimal solution, CSs are assigned specific time periods to be active. Therefore, the links in those CSs can transmit for such optimized time periods [12].

For clarity, we divide this section into different subsections as follow:

A. LINK ACTIVATION (LA)

In this subsection we propose solutions on how to optimize the set of communication links from CMs to CH that can communicate simultaneously. A link is activated means the communication link is established. Optimizing the active links is the main task in transmission scheduling and bandwidth allocations. Here, communication links are assigned a nonnegative weight and the goal is to maximize the overall weight. A set of active links are named CS [11, 13, 14]. The scheduling of transmissions can be realized by allocating different optimized time periods to the different CSs. Therefore, LA problem is the main part for transmission scheduling. In LA, we consider the interferences from other transmitters as additive noise.

We propose a BIP solution to have an optimal LA as below:

$$\max \sum_e L_e \ , e \in \varepsilon . \tag{3}$$

Equation (3) is the objective function which maximizes the total number of active links. To each link e, a variable L_e is assigned which specifies whether this link is active or not. L_e is an integer variable (0 or 1).

Only one of link to node v can be active at each node:

$$\sum_{e \in \delta(v)} L_e \ \leq 1 \ , v \in V. \tag{4}$$

A node can be active when transmitting and its corresponding link is active:

$$\sum_{e \in \delta^{+}(v)} L_e \ = n_v \ , v \in V. \tag{5}$$

In (5), to each node v, a variable n_v is assigned which specifies whether this node is active or not. $\boldsymbol{n_v}$ is an integer variable (0 or 1).

Link e can be activated when SINR ratio of link e is higher than or equal to a specific threshold defined for that link:

$$\frac{p_{a(e)b(e)}}{N + \sum_{v \in V \setminus \{a(e)\}} \ p_{vb(e)}} \geq \ \gamma_e \ , e \in \ \varepsilon. \tag{6}$$

In (6), $p_{a(e)b(e)}$ is the received power at node b when node a of link e is transmitting towards it. $\sum_{v \in V \setminus \{a(e)\}} \ p_{vb(e)}$ is received power at node b from all other active node excluding node a. γ_e is SINR threshold defined for link e. N is noise power density.

Equation (6) should be considered when link L_e is active. For this purpose, we multiply L_e on both sides of equation. We also multiply n_v by the dominator of the equation, to only consider interferences from active nodes:

$$\frac{p_{a(e)b(e)} \ L_e}{N + \sum_{v \in V \setminus \{a(e)\}} \ p_{vb(e)} \ n_v} \geq \ \gamma_e L_e \ , e \in \ \varepsilon. \tag{7}$$

Equation (7) is not solvable (equation is not linear since two integer variables are multiplied). We use "big H Method" method for solving this issue:

$$\frac{p_{a(e)b(e)} + H_e(1\text{-}L_e)}{N + \sum_{v \in V \setminus \{a(e)\}} \ p_{vb(e)} n_v} \geq \ \gamma_e, e \in \ \varepsilon \ . \tag{8}$$

$$H_e = N\gamma_e + \sum_{v \in V \setminus \{a(e)\}} \ p_{vb(e)} n_v \ \gamma_e \text{-} p_{a(e)b(e)} \ , e \in \ \varepsilon$$

As shown in (8), equation can be made linear by introducing big H notation [12]. H is big enough to help the equation to be always satisfied whenever the link e in not active.

We can use link multiplication instead of node multiplication.

$$\frac{p_{a(e)b(e)} + H_e(1\text{-}L_e)}{N + \sum_{f \in E \setminus \{e\}} \ p_{a(f)b(e)} L_f} \geq \ \gamma_e, e, f \in \ \varepsilon \ . \tag{9}$$

$$H_e = N\gamma_e + \sum_{f \in E \setminus \{e\}} \ p_{a(f)b(e)} \ \gamma_e \text{-} p_{a(e)b(e)} \ , e, f \in \ \varepsilon$$

B. FLOW SHARING

In this subsection we propose solutions on how we can maximize data delivery from CMs to CH during data delivery time. The data delivery passes through different subsets of active links described in the previous subsection. For this purpose we formulate Max-Min flow allocation problem. We try to maximize the minimum traffic flow (f) on a route from on CM to the CH. In this work we assume each route to be a two-hop route at most.

Before moving to the formulation part we need to define some new variables. We used the same notations as some previous works [12, 11, 14].:

Let r= $\{r_1, r_2, r_3, .. r_e\}$ denote the number of routes going through the corresponding link. The product $r_e f$ is called load of link. Link capacity reservation variables is c= $(c_e : e \ \in \ \varepsilon)$. CS is a set of active links and is calculated from the previous section. CS can be defined by ε_i= $\{ \ e \ \in \ \varepsilon; L_e$=1$\}$ for any set of feasible link variable L_e , $e \in \varepsilon$. We call subset C as compatible set C_i , $i \in I$, (where $I = \{1,2, \dots, I\}$). I is the given list of compatible sets and z_i indicates the time duration where the C_i (CS i) is actually used $\sum_{i \in I} z_i = T$. D is the assigned data rate. The total amount of data that can be sent over link e during time T is equal to $\sum_{i \in I} z_i D_{ei} = c_e$, where D_{ei}=D if $e \in C_i$, and D_{ei}=0 if not $e \in C_i$, D_{ei} is the rate assigned to link e in compatible set i. f is the amount of the flow that each CM can deliver to the CH.

Max-min flow allocation problem- For the given set of C_i , $i \in I$, we define an optimization problem which tries to maximize the minimum traffic flow on a route.

The formulation are expressed below. We call this part of formulations as master problem (MP) [11, 14]:

$$\text{Maximize } f$$

$$r_e f \leq c_e, e \in \varepsilon \quad (10)$$

$$[j_e] r_e f \leq \sum_{i \in I} z_i D_{ei}, e \in \varepsilon, i \in I \quad (11)$$

Equation (11), ensures that the total amount of data sent over link e (denoted by $r_e f$) does not exceed the capacity c_e or $\sum_{i \in I} z_i D_{ei}$, $e \in \varepsilon, i \in I$.

The object shown in bracket represents dual variable. Let j_e be an optimal solution of dual problem.

$$\sum_{i \in I} z_i = T \;, z_i \geq 0, i \in I \quad (12)$$

Equation (12) shows that, the total time (T) will be divided between operating sets C_i , $i \in I$.

A CS is generated by solving the bellow equation. From now on, we call this part of formulation as sub-problem.

$$\max \sum_{e} L_e j_e \quad , e \in \varepsilon \quad (13)$$

The algorithm is as follow:

Step 1: Initial set of CS will be given to MP to be solved.

Step 2: Sub-problem will be solved and the new CS will be generated.

Step 3: CS will be added to the MP and will be solved again.

Step 4: If multiplication of the j_e ,with existing CSs is smaller than or equal to objective of the sub-problem, then we add a new CS, unless iteration stops.

V. TRANSMISSION PLANNING

The ideal transmission scheduling that we anticipate from our optimization problem can be defined by carefully dividing the total operation time to the different optimized sets of active links obtained from the previous subsection. Our idea for applying transmission planning is to use time slot schemes and define the transmission plan for each node. This can be realized with a centrally preplanned transmission coordinator (CH). CH broadcasts the transmission scheduling information to CMs.

For better understanding, suppose that we have two CMs delivering data to their assigned CH during T. Two links (link 1, link2) may be activated for duration of T/2 ($Z_{1,2}$ =T/2ms) in perfect conditions. We may divide T to N time slots. Therefore, the first time slot is assigned to link one, second time slot is assigned to link two and so on, up to N. It is useful to divide the compatible set times to small time slots in case there is multi-hop.

VI. SIMULATION RESULTS

In this section, we present the performance evaluation and simulation results for our proposed distributed cluster based (DCB) transmission scheduling in terms of delivered throughput and achieved delay upon delivering packets. Here, our proposed optimization method is compared to CSMA/CA and VDA [10].We consider two vehicular networks with different vehicle densities, low and high, in three lanes highway. The number of vehicles in low and high density networks are 2 and 12 vehicles per kilometer per lane, respectively. The transmitting power is the same for all vehicles, that is 5 mw or in logarithmic scale 7 dBm. We also assume the case 802.11p operating with an OFDM PHY in 5.9 GHZ band. Other main parameters are listed in Table 1. For evaluating our proposed optimization model, clusters are formed beforehand and CHs and CMs are selected using the approach in [15] where each CM is at most two- hops away from a CH.

Table 1 Simulation parameters

Parameter	Value
Modulation	BPSK
Coding rate	1/2
Raw bitrate	1to 6 Mbps
Propagation model	Nakagami
Transmitting Power	7 dBm
Noise power density	-131 dBm
System bandwidth	10 MHz
Simulation time	10 sec
Message payload size	500 byte
Vehicle speed	40 km/h

Illustrated results were obtained from MIP models implemented using python 2.7.9 with Gurobi optimizer v 6.0.5 [16] and executed on core i5 2.4 GHZ CPU with 8 GB RAM, Windows PC. We used network simulator NS-2 for simulations in order to compare the obtained results with ordinary MAC (CSMA/CA) and VDA. VDA is a deterministic medium access control which schedules transmissions in contention free periods within a two-hop neighborhood. Two-hop clusters are formed, as vehicles travel on the road. For our optimization model, CH takes the responsibility of scheduling transmissions in the network, while in VDA, scheduling is based on vehicles' negotiations with each other in a two-hop neighborhood.

To evaluate our transmission scheduling scheme, we consider the following metrics: (1) the average throughput: is the average amount of data which is delivered from CM vehicles to the specified CH during the simulation time; (2) the average end to end delay: is the average delay for delivering packets from CMs to CH.

A. The average throughput

Figure 1 shows the variation of the average throughput for different values of the offered load. As shown in the figure, the average throughput improves by increasing the offered load. For our DCB transmission scheduling, this increase in throughput value is almost linear. Whereas, in VDA and CSMA/CA, by increasing the offered loads, the average throughput remains almost constant for the offered loads higher than 4 Mbps (low density). This can be explained by the fact that in DCB, the transmission links have been optimally scheduled in order to decrease the interferences effect. For this purpose, different subset of links are activated for different time periods in order to achieve the highest possible flow (throughput) based on the proposed optimization solution. In CSMA/CA, each transmitter senses the channel before transmitting. Therefore, lots of packets will be queued to avoid the collisions whenever the transmitting nodes are in the sensing range of each other. The hidden terminal node is also another problem in CSMA/CA which leads to collisions in the network. In our scheduling method, the CH is responsible for broadcasting the transmissions scheduling information in the constructed clusters, therefore the hidden node problems can be alleviated. In VDA, scheduling is deterministic but hidden node and interference problems still remain, as each node schedules transmissions by negotiating with its neighbour vehicles. The differences in throughput can be easily observed in the high density scenario rather than low density scenario as the interference effect and hidden problem node effects have more impact on the network.

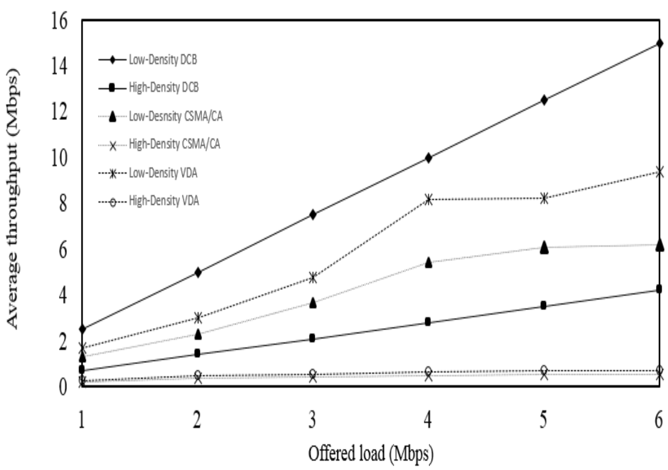

Figure 1 Average throughput.

B. The average end to end delay

The average end to end delay is shown in figure 2. The delay decreases by increasing the network offered load. This decrease is higher in our proposed DCB transmission scheduling. The reason for lower delay decreases is similar to the average throughput case, having higher contentions as the offered load increases. The transmitters in CSMA/CA schedule transmissions in their sensing range. Therefore, contentions can happen as vehicles transmit without consideration for transmitting vehicles that are not in sensing range of themselves. Whenever the vehicles sense the collisions, they choose a random back off which increases the delay upon delivering packets. This random back off increases whenever the channel is sensed busy. Although the random back off problem has been solved in VDA, the hidden node and interference problems still remain which cause collisions and delay increase upon delivering packets. These problems are addressed in our proposed transmission scheduling method by having a transmission scheduler (CH) which integrates the physical condition of the network in scheduling. This comes, of course, at the expense of having to use a clustering scheme prior to scheduling optimisation and transmission planning. We can also notice, that the delay upon delivering packets increases as the number of vehicles increases. This can be explained by the fact that, the waiting time to access the medium increase as the network gets denser.

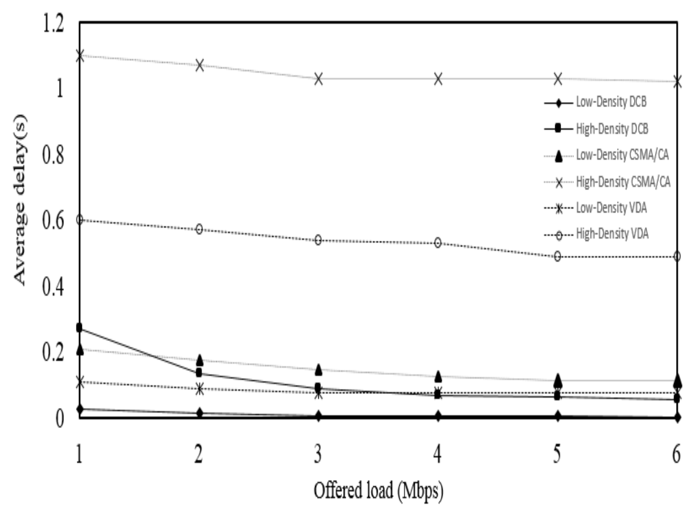

Figure 2 Average end to end delay.

VII. CONCLUTION

In this paper a distributed cluster based (DCB) transmission scheduling is presented. This scheme provides a contention free transmission scheduling for the clustered vehicles to access the medium. To implement the proposed scheme, a non-compact mathematical optimization model is introduced which addresses the Max-Min flow allocation problem. Based on the simulation results, DCB transmission scheduling improves the network performance in terms of throughput and delay.

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