Bus-Ads: Bus-based Priced Advertising in VANETs using Coalition Formation Game

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Abstract—Advertising among vehicles has become popular with the proliferation of vehicular ad-hoc networks (VANETs). Since the price of the advertisements broadcast in such networks decay over time, distributing advertisements with a high price value to more private vehicles can generate more revenues to the sellers. In this paper, we consider a bus-based priced advertising scenario in a VANET, in which the buses act as the sources of advertisements and broadcast advertisements to private vehicles running within their communication range. Meanwhile, in the area where no bus exists, private vehicles share their advertising segments. The manner in which the buses and the private vehicles distribute and share advertisements in the network so as to draw the largest benefit is addressed in our formulated problem. To solve this problem, a bus-based priced advertisement dissemination scheme dubbed Bus-Ads is proposed by using coalition formation game. First, a bus-broadcast method is presented to enable each bus to distribute the priced advertising segments with the largest potential benefit to surrounding private vehicles. Second, we apply coalition formation game to guide private vehicles to construct broadcast coalitions for efficient advertisement sharing. Simulation results demonstrate that our proposed Bus-Ads method can achieve about twice the total benefits compared with that of the non-coalition-based approach.

Keywords—Vehicular advertising; VANET; coalition formation game.

I. INTRODUCTION

Recently, Vehicular Ad-hoc Networks (VANETs) are anticipated to play an important role in our life. In VANETs, advertising among vehicles is a promising application, which can apprise the drivers and passengers of the features of products and information on sales promotions, and thus, bring commercial benefit to the sellers. Some researchers have already visualized similar scenarios [1]–[4]. In order to distribute advertisements to the vehicles, in VANETs, some nodes have to act as the sources of advertisements through pre-fetching the advertisements from the Internet. In some metropolises, buses are quite common on the road. Furthermore, buses have fixed routes (i.e., trajectories) in cities, and therefore, they can easily disseminate advertisements to “private vehicles” while driving in close proximity. Therefore, the buses can be regarded as suitable advertising sources in VANETs. In this paper, we refer to the vehicular advertising whereby buses act as the sources of advertisements as the “bus-based vehicular advertising”.

The main task of bus-based vehicular advertising is to distribute advertisements from buses to private vehicles to earn the highest benefits. The advertisements carried by buses are composed of a large amount of “advertising segments”. An advertising segment can be a picture or video of a sales promotion with time restriction about one merchandise. For instance, an advertising segment could be a trailer of a film. A person who previews the trailer earlier has more chances to watch the entire film. The time restriction of the sales promotion makes the advertising segment having a time-sensitive price value. The benefit for a private vehicle receiving an advertising segment is defined as the remainder price value of the segment minus the communication expense, which is paid to the senders as incentive of the advertisement transmission. Large benefits obtained by private vehicles indicate that many advertisements with high remainder price values are distributed to many vehicles, and huge potential revenues will be brought to advertisers. Therefore, by which manner the buses and the private vehicles distribute and share advertisements in the network can draw the largest benefits becomes the critical question for implementing an effective bus-based priced advertising application in VANET.

In this paper, to solve the above-mentioned question, we propose a bus-based priced advertisement dissemination scheme in VANET, referred to as the “Bus-Ads”. The scheme includes two phases. The first phase is the bus broadcasting phase. In this phase, a bus searches for and broadcasts the most suitable advertising segment to private vehicles in its communication range. The second phase is the advertising segment sharing among private vehicles. In this phase, we apply coalition formation game to guide private vehicles formulate broadcast coalitions. For each private vehicle in a broadcast coalition, we analyze the most suitable segment which should be broadcast from it in order to maximize the total benefits obtained by all the receivers. Simulation results demonstrate that the Bus-Ads method is able to achieve approximately twice the total benefits obtained for private vehicles compared with those acquired by the non-coalition-based approach.

The contributions of this paper are listed as follows.

- We model the bus-based advertising in VANET, where each advertising segment is attached with a time-sensitive price value and the buses act as the advertisement sources.
- We present a selection mechanism for buses to choose the most valuable segments wanted by their surrounding private vehicles, and apply coalition formation game to guide private vehicles to construct broadcast coalitions to avoid interference and facilitate the vehicular advertising process.
- We conduct extensive experiments to show that the coalition game theory can earn about twice the benefits in contrast with the non-coalition-based method.
The remainder of the paper is organized as follows. In Section II, we introduce the relevant research works. Section III describes the bus-based priced vehicular advertising in VANET. In Section IV, we model the priced advertising segment sharing among private vehicles as a coalition game. In Section V, we present the coalition formation game-based advertisement dissemination scheme, which contains a bus broadcasting part and a private vehicle sharing part. Simulation results are presented in Section VI. Section VII concludes the paper.

II. RELATED WORKS

In the work conducted in [5], the authors applied coalitional graph game to guide the vehicles form a peer-to-peer network where one vehicle transmits segments to multiple vehicles, but receives from only a single vehicle for sharing popular content. Additionally, the work proposed a myopic dynamic method for the network formation of the coalitional graph game. In the work conducted in [6], the popular content distribution problem in a highway scenario was addressed. In that work, the problem was modeled as a coalition formation game, and a coalition formation algorithm was proposed to solve the problem. On the other hand, in [7] [8], network coding was applied to facilitate the content downloading in VANETs for the efficiency in transmissions and simplicity in scheduling. A content distribution system without investment, referred to as ParkCast, was introduced in [9], which leverages roadside parking to distribute contents in urban VANETs. However, those previous works are unable to directly address the bus-based priced advertising problem for two reasons. The first reason is that the message sources of those articles, i.e., RSUs, are fixed on the side of roads. However, the message sources in the bus-based priced advertising problem, i.e., buses, are moving and have large communication coverage through their movements. Hence, there should be a different broadcasting scheme for the message sources in the bus-based advertising scenario. The second reason is that, in the existing works, the amount of data received by vehicles is a major concern. However, in the bus-based advertising problem, we attach with each data (i.e., an advertising segment) a time-sensitive price value so that the vehicles who help to broadcast advertisements get paid for communication, and the target is to maximize the total benefits obtained by all vehicles in the network.

In [3], [4], commercial advertisement dissemination in vehicular networks was analysed supposing that private vehicles are selfish. Incentive schemes were proposed to facilitate the advertisement dissemination. However, in this paper, we suppose that private vehicles are cooperative and altruistic, we focus on how those private vehicles collaborate to obtain more advertisement.

III. BUS-BASED ADVERTISING IN VANET

In this section, we describe the scenario of the bus-based advertising in VANET.

A. Overview

Consider a network where $q$ buses, and $l$ private vehicles are running on the road. The buses are supposed to have the same advertising files. For instance, there are $m$ advertising segments, denoted by $\Gamma = \{\gamma_1, \gamma_2, \ldots, \gamma_m\}$. The buses act as sources and broadcast the advertising segments to the surrounding private vehicles. Private vehicles are supposed to be willing to receive those segments. Due to the differences between the velocity of buses and private vehicles, private vehicles may receive all or a part of segments from a bus during contact with buses. In an area where no bus exists, private vehicles exchange segments with one other to obtain more advertising segments and benefits.

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{figure1.png}
\caption{The price value of advertising segments.}
\end{figure}

\begin{equation}
\rho_{\gamma}(t) = \rho_{\gamma} - \delta \cdot t,
\end{equation}

where $\delta$ is the price value decay coefficient, which means the decreased price value within each unit time interval.

Transmission costs occur when segments are being broadcast. Let $c_{i,\gamma}$ denote the cost spent by vehicle $i$ for receiving segment $\gamma$, and then the benefit for receiving segment $\gamma$ by the receiver $i$ satisfies:

\begin{equation}
\beta_{i,\gamma} = \rho_{\gamma}(t) - c_{i,\gamma}.
\end{equation}

C. The bus-based advertising

We assume that all buses and private vehicles are running on the road as shown in Fig. 2. The buses have specified trajectories on the main roads while the private vehicles are supposed to run on the main roads or service roads. When one bus exists in an area, the bus broadcasts advertising segments to surrounding private vehicles. When no bus exists in an area, the private vehicles exchange the advertising file with one other to obtain more advertising segments and benefits.

For the bus broadcast, we suppose that every bus has a higher antenna and has a larger coverage compared with
We use $D$ to represent a group of private vehicles. The private vehicles in $D$ are supposed to be cooperative and altruistic and want to share their advertising segments. In group $D$, a part of vehicles form a broadcasting coalition. It should be noted that the utility of a coalition is defined as the total residual price values of the advertising segments transmitted to the members of the group. This definition means that the coalition members want to transmit more valuable advertising segments to other group members so that they can receive more valuable advertising segments when other group members are broadcasting. Using $S$ to represent the broadcasting coalition, we explore the largest utility of the coalition by choosing the most proper segment to broadcast for each private vehicle in coalition $S$. Private vehicle $i \in S$ can only disseminate a segment to its “alive neighbors”. The set of “alive neighbors” is given by,

$$X_i^* = \{ j \in X_i | \theta_{i,j} \geq \varphi, (X_i \setminus \{i\}) \cap S = \emptyset \}, \quad \forall i \in S,$$  

where $X_i$ are the neighbors of private vehicle $i$ and $\varphi$ is the data size of an advertising segment. For a private vehicle $i \in S$, the most proper segment to broadcast for private vehicle $i$ is given by,

$$\gamma_i^* = \arg \max_{\gamma \in \Gamma} \sum_{j=1}^{X_i^*} R_{i,\gamma} \cdot \rho_{\gamma}(t) |_{\gamma}, \quad \forall i \in S.$$  

After choosing the most proper segment to broadcast for each private vehicle in coalition $S$, the advertising segments received by the private vehicles in group $D$ from the senders in the coalition $S$ are certain, and the total residual price value of all the segments received by the private vehicles in $D$ from the senders in $S$ can be calculated. The largest utility coalition $S$ can bring to the group is given by,

$$U(S) = \sum_{i=1}^{k} \mu_{i,S}(i),$$  

where $k$ denotes the number of private vehicles in the group $D$, and $\mu_{i,S}(i)$ is the utility brought to vehicle $i$ by coalition $S$ through transmitting a segment at time-interval $t$, which may be expressed as follows,

$$\mu_{i,S}(i) = \sum_{\gamma \in \Gamma} (\rho_{\gamma}(t) \cdot R_{i,\gamma,S}),$$  

where $R_{i,\gamma,S}$ is a parameter to indicate whether segment $\gamma$ is received by vehicle $i$ at time-interval $t$ when the private vehicles in the coalition $S$ are broadcasting advertising segments.

**Fig. 2.** The road traffic model composed by buses and private vehicles.

private vehicles and the private vehicles in its coverage can successfully receive the broadcasting. For the private vehicle to private vehicle channels, we assume that the transmitting signal from any private vehicle $j$ can be received only by its neighbors, where Lines of Sight (LoS) exist between them and the transmitting vehicle. For the existing links, we consider the path-loss only with large-scale fading, and the channel capacity between private vehicles $a$ and $b$ is directly given by [11],

$$\theta_{a,b} = \begin{cases} W \log_2(1 + \eta d_{a,b}^{-n}) \text{, } & \text{LOS exist} \\ 0, & \text{otherwise} \end{cases},$$

where $W$ is the bandwidth, $n$ is the pathloss exponent, $d_{a,b}$ is the distance between the private vehicles $a$ and $b$. Furthermore, $\eta$ represents signal-to-noise rate (SNR) at the transmitter.

**IV. ADVERTISEMENT SHARING AMONG PRIVATE VEHICLES AS A COALITION GAME**

In the private vehicle sharing process, if private vehicle to private vehicle links are established randomly in an inharmonious manner, interference will occur when a private vehicle receives the signals of two or more private vehicles. Thus, the advertising segments shared among the private vehicles may suffer from a low data throughput and a limited benefit increase. We apply the coalition formation game to guide the private vehicles to formulate broadcasting coalitions, as shown in Fig. 2, to avoid interference and facilitate advertising segment sharing process.

**A. Utility Function of a Coalition**

To simplify the analysis of the private vehicle sharing problem, we divide the private vehicles into groups where group members are near to each other. In each group, some private vehicles can form broadcasting coalitions, and the utility of a broadcasting coalition is described in detail below.

$$\theta_{a,b} = \begin{cases} W \log_2(1 + \eta d_{a,b}^{-n}) \text{, } & \text{LOS exist} \\ 0, & \text{otherwise} \end{cases},$$

where $W$ is the bandwidth, $n$ is the pathloss exponent, $d_{a,b}$ is the distance between the private vehicles $a$ and $b$. Furthermore, $\eta$ represents signal-to-noise rate (SNR) at the transmitter.
B. Coalition Game

Definition 1: A coalition game with non-transferable utility for the segment sharing problem among the private vehicles is defined by a pair \((D, V)\), where \(D\) is the set of game players and \(V\) is a set of payoff vectors. An element \(\phi_i(S)\) of a vector
\[\phi(S) \in V(S) \subseteq \mathbb{R}^{[S]}\]
represents a payoff that player \(i \in S\) can obtain within coalition \(S\) given a certain strategy selected by \(i\) while being a member of \(S\).

The private vehicles are cooperative and altruistic in a group, and they want to construct the broadcasting coalition which can bring the largest total benefits to the members of the group. So, we suppose that the payoff for each coalition member in \(S\) as the utility of coalition \(S\) minus the cost of coalition \(S\). The cost for coalition \(S\) is defined as the communication cost for broadcasting, which is related to the number of the coalition members and is given by,

\[C(S) = \alpha|S|,\]

(8)

where \(\alpha\) is the pricing factor for a broadcasting process. Therefore, we can calculate the payoff of coalition member \(i \in S \subseteq D\) by subtracting the cost of \(S\) (8), from the utility of \(S\) (6), which is given by,

\[\phi_i(S) = U(S) - C(S), \quad \forall i \in S.\]

(9)

The value of coalition \(S\) is also defined as the utility of \(S\) minus the cost of \(S\), i.e., \(V'(S) = U(S) - C(S)\). In the proposed private vehicle sharing problem, the grand coalition \(D\) has no utility because when all private vehicles are broadcasting, absolutely no private vehicle has "alive neighbors" due to the serious interference. Furthermore, the grand coalition has a large communication cost for the advertising segment broadcasting. Thus, the value of the grand coalition is negative, which indicates that the grand coalition for a group of private vehicles will hardly form. For any coalition composed by only one private vehicle \(i \in D\), we assume that the private vehicle only broadcasts an advertising segment when \(U\{\{i\}\} > \beta\). Therefore, the single player coalition always has a non-negative value \(V'(i) = U\{\{i\}\} - C\{\{i\}\}\). When multiple private vehicles form a broadcasting coalition, if the interference among those coalition members is small, the value of the coalition will be larger than that of the single player coalitions. Therefore, the coalition which has the largest value is probably composed by a part of private vehicles. When there are \(k\) members in a group of private vehicles, the number of different coalitions is \(C_k^1 + C_k^2 + C_k^k = 2^k - 1\). It is hard to calculate and compare the values of all possible coalitions. Therefore, it is challenging to find out the coalition of private vehicles that has the largest value. To solve this problem, in Section V-B, we apply a join-and-split rule to guide a group of private vehicles form broadcasting coalitions which are local optimal.

V. PROPOSED ADVERTISEMENT DISSEMINATION METHOD: BUS-ADS

In this section, we propose our coalition formation game-based advertisement dissemination method dubbed the Bus-Ads. The proposed method consists of two parts, namely the bus broadcasting and private vehicle sharing parts, which are described below.

A. Bus Broadcasting Phase

In the first phase, we suppose that only one bus exists in an area to simplify the analysis. Therefore, the private vehicles in the coverage of the bus can receive the broadcast signal without interference from other buses. Furthermore, we suppose that when a bus exists in an area, private vehicles stop exchanging segments with one other. We aim at increasing the total benefits obtained by all private vehicles in the coverage of the bus. The total benefits can be defined as the total residual price values of the received advertising segments minus the transmission cost of the bus for broadcasting, which is given by,

\[\beta_{bus}(t) = \left(\sum_{i=1}^{N} R_i,\gamma(t) \cdot b_i(t)\right) - c_{bus},\]

(10)

where \(N\) denotes the number of private vehicles in the coverage of the bus, \(R_i,\gamma(t)\) is a parameter to indicate whether segment \(\gamma\) is received by vehicle \(i\) from the bus at time-interval \(t\), \(c_{bus}\) is the communication cost for the broadcasting of the bus that will be spent by the private vehicles which receive the segment \(\gamma\) at time-interval \(t\).

We suppose that a bus has the knowledge pertaining to which part of segments is possessed by each private vehicle within the coverage of the bus. So, for broadcasting, the bus chooses the segments which will bring the most utility to the private vehicles in its coverage. The segment \(\gamma^*\) which is selected by the bus to broadcast is given by,

\[\gamma^* = \arg\max_{\gamma \in \Gamma} \sum_{i=1}^{N} R_i,\gamma(t) \cdot b_i(t)\]

(11)

In other words, the bus takes the residual price value of each advertising segment as well as the number of private vehicles lacking the advertising segment into account in order to choose the most appropriate segment.

B. Private Vehicle Sharing Phase

In the second phase, to simplify the analysis, we divide the total vehicles into groups for every specified distance. In each group of private vehicles, we design a switch rule to guide private vehicles to form broadcasting coalitions.

When a private vehicle in the edge of a group broadcasts a segment, some private vehicles in the adjacent groups will be interfered. So, we restrict the edge private vehicles from broadcasting. Private vehicles which are not at the edge of the group form non-overlapping broadcasting coalitions \(\Pi = \{S_1, ..., S_l\}\), and \(\bigcup_{l=1}^{N} S_k = D'\) where \(D'\) represents a group of private vehicles which are not at the edge of the group. We define the coalition where private vehicle \(i\) belong to by \(S_{\Pi}(i)\). In each group of private vehicles, given current broadcasting coalitions, private vehicles which are not at the edge of the group can decide to split from one coalition and join into another one to maximize their own payoffs as follows.
Switch Rule: Given a broadcasting coalition combination \( \Pi = \{S_1, ..., S_l\} \) of a group of private vehicles, a switch operation from \( S_l \in \Pi \) to \( S_k \in \Pi \setminus \emptyset, S_k \neq S_l \) is allowed for any player in \( D^i \) when the following conditions exist,

\[
\phi_i(S_k \cup \{i\}) > \phi_i(S_l(i)), \quad (12) \\
\phi_j(S_k \cup \{i\}) \geq \phi_j(S_k), \quad \forall j \in S_k, \quad S_k \cup \{i\} \notin H\{i\},
\]

where \( H\{i\} \) is defined as the set of coalitions that private vehicle \( i \) visited and left.

Starting from an initial broadcasting coalitions combination, any private vehicle can decide to leave or join into current broadcasting coalitions by the switch rules. According to the switch rule, each switch operation will yields an unvisited broadcasting coalition combination. As the number of the combinations for a given group of private vehicles is finite, the switch operations will always terminate and converge to a final broadcasting coalitions combination after finite turns.

In the converged broadcasting coalitions combination, the coalition with the largest value \( V' \) obtain the broadcasting right. This final broadcasting coalition is a local optimal solution for the private vehicle sharing problem. In other words, individually adding a private vehicle into the final broadcasting coalition or individually removing a member from the final broadcasting coalition will reduce the value of the final broadcasting coalition. Then, each member of the final broadcasting coalition broadcasts the most proper advertising segment calculated through equations (4) and (5). To adapt to the changing network topology, the bus broadcasting and the private vehicle sharing phases are repeated in each time interval. A summary of the entire advertisement dissemination method composed of these two phases is shown in Table I.

### VI. SIMULATION RESULTS

In this section, the performance of the proposed advertisement dissemination scheme, i.e. Bus-Ads, is simulated and compared with two other schemes: a non-coalition-based scheme and the popular content distribution (PCD) scheme in [6]. In the non-coalition-based scheme, each private vehicle chooses the advertising segment which can bring the largest benefit to surrounding vehicles and broadcasts the chosen segment with a probability related to the benefit which can be brought to surround vehicles. In the PCD scheme, coalition game theory is applied but time varying prices of advertising segments are not taken into account. The simulation scenario is similar to the scenario in Fig. 1, where one bus travels from the left bottom to the right top and broadcasts vehicular advertisements to surrounding private vehicles. We only consider that one bus exists in the scenario to avoid interference between buses. In the area where the bus broadcasting cannot be received, private vehicles share advertising segments with each other. We assume that the time-interval is one second, and the bus can broadcast one advertising segment to the private vehicles within its communication range every four seconds. The detailed parameters are listed in Table II.

The total benefits of all private vehicles of three schemes are shown in the Fig. 3. As shown in the figure, our scheme exhibits the best performance with the largest total benefits. The good performance of our proposal can be credited to the fact that in each group of private vehicles, only the private vehicles in the broadcasting coalition can broadcast so that a lot of interferences and data collisions are avoided. Additionally, in each group of private vehicles, we form the local optimal broadcasting coalition and select the most suitable advertising segment to broadcast for each member of the coalition. In the PCD scheme, time-varying prices of advertising segments are not considered, so high priced segments do not have a priority than those low priced segments, and the achieved total benefits are smaller than the Bus-Ads scheme. In the non-coalition-based scheme, each private vehicle decides to broadcast the advertising segments possessed by itself without coordination with others. Therefore, a lot of interferences and data collisions occur when some adjacent private vehicles broadcast simultaneously, and consequently, the increase of

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**TABLE I. THE ADVERTISEMENT DISSEMINATION SCHEME (BUS-ADS)**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of private vehicles (l)</td>
<td>100</td>
</tr>
<tr>
<td>Number of segments (s)</td>
<td>10</td>
</tr>
<tr>
<td>Length of main roads</td>
<td>1000 meters</td>
</tr>
<tr>
<td>Length of service roads</td>
<td>10000 meters</td>
</tr>
<tr>
<td>Diameter of the coverage of the bus</td>
<td>200 meters</td>
</tr>
<tr>
<td>Bandwidth of private vehicles (MHz)</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Exponent for pathloss ((\eta))</td>
<td>4</td>
</tr>
<tr>
<td>Signal-to-noise rate at the transmitter ((\rho))</td>
<td>10^6</td>
</tr>
<tr>
<td>Size of the advertising segment ((\Phi))</td>
<td>2 Mbit</td>
</tr>
<tr>
<td>Length of vehicle groups</td>
<td>200 meters</td>
</tr>
<tr>
<td>Velocity of the bus</td>
<td>8 - 10 meter/second</td>
</tr>
<tr>
<td>Velocity of private vehicles</td>
<td>10 - 15 meter/second</td>
</tr>
<tr>
<td>Initial price value of advertising segments ((\rho_0))</td>
<td>30 or 15</td>
</tr>
<tr>
<td>Price value decay coefficient ((\delta))</td>
<td>0.06 or 0.03</td>
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</tbody>
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**TABLE II. PARAMETERS FOR SIMULATION**

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**Fig. 3. The total utility of all private vehicles vs. time.**

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are transmitting, only a few of the transmitted advertising segments possessed by itself without a coordination based method, each private vehicle decides to broadcast the signal of only one sender, the private vehicle can receive the signal of only one sender, the private vehicle can receive the signals of more than one sender, the private vehicles that do not obtain all segments require the broadcasting from others.

The number of private vehicles receiving a segment successfully from other private vehicles over time is demonstrated in Fig.5. We suppose that when a private vehicle receives the signal of only one sender, the private vehicle can receive the signal successfully. On the other hand, when a private vehicle receives the signals of more than one sender, the private vehicle cannot receive those signals because of interference. As seen in the figure, for the proposed Bus-Ads method, the number of private vehicles successfully receiving a segment is better than the non-coalition-based method. The reason is that in the Bus-Ads method, only the private vehicles in the broadcasting coalition can broadcast, so that interference and data collisions are avoided and a lot of broadcasts can be successfully received. On the contrary, in the non-coalition-based method, each private vehicle decides to broadcast the advertising segments possessed by itself without a coordination with others. Therefore, although a lot of private vehicles are transmitting, only a few of the transmitted advertising segments can be successfully received.

VII. Conclusion

In this paper, we proposed a bus-based priced advertisement dissemination method based on coalition formation game in VANET that is referred to as the Bus-Ads. The proposed method includes two phases, namely the bus broadcasting and the private vehicle sharing phases. In the bus broadcasting phase, the most appropriate advertising segment for the bus at each time-interval is chosen in order to improve the performance of the vehicular advertising process. In the private vehicle sharing phase, coalition formation game is applied to guide the private vehicles to construct broadcast coalitions for effective advertisement sharing. Simulation results demonstrated that the Bus-Ads scheme can achieve about twice the total benefits for private vehicles compared with that of the non-coalition-based approach.

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