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# Utility-Based Forwarder Selection for Content Dissemination in Vehicular Networks

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**Abstract**—Recent work has shown that content dissemination protocols in vehicular networks can achieve throughput and fan-out delay optimization by either simple network flooding or destination-driven dissemination. While those content dissemination schemes work well, they require all nodes in the network to forward every data packet, which has inherent inefficiencies for non-flooding traffic patterns, where not all nodes need to receive the data. Hence, they support adequately safety applications, being not efficient for non-safety applications, whereby the flow of information is interest-driven rather than destination-driven, e.g. restaurant recommendation and sale advertisement. In this work, the concept of “useful” forwarder is formalized aiming at maximizing content utility for end users. Further, it presents I-SEND, a forwarder selection approach, which enables nodes to choose the most appropriate forwarders. Incorporating I-SEND on trace-driven and synthetic simulation scenarios can produce higher content utility than other concurrent schemes.

## I. INTRODUCTION

Vehicular networks have become an emerging paradigm for content dissemination [1]. They support the transmission and generation of a massive amount of data by day such as traffic information, available parking places, restaurant recommendation, sale advertisement, and others. However, users are seldom interested in all these data; they only want a small part of the information. Nowadays, with the growing popularity of personalized applications, customers prefer to get data based on their personal interests. Moreover, vehicular networks consist of highly mobile vehicles communications, where connectivity is intermittent and exists only during a very short period, constraining them to exchange a limited volume of data on each contact. Thus, there is an increasing demand for content dissemination that addresses not only the efficient use of network resources and positive fan-out delay, but also maximizes *content utility*, i.e. the benefits that users can have by receiving the content.

Several approaches for content dissemination in vehicular networks are either flooding-based or destination-driven. In general, either they have a set of specific destinations and thus, aim to optimize throughput and fan-out delay by selecting the most appropriate next-relays; or they flood the network, requiring all nodes forward each data packet. Several works consider network properties including centrality and communities to choose next relay nodes. Thus, these schemes enable to reach destinations in a short delay. However, for non-safety applications, content dissemination is a communication paradigm whereby the flow of information is interest-driven rather than destination-driven, e.g. restaurant recommendation,

sale advertisement. Hence, choosing the forwarder that can produce higher content utility and thus maximally satisfy users interests lies in a challenge.

This paper presents I-SEND, an Utility-based forwarder selection approach for content Dissemination in vehicular network. Differently from other approaches, I-SEND aims to improve content utility on end users, i.e., the benefits that users can have receiving a content, by choosing the most appropriate forwarder when vehicles meet opportunistically, without compromising the performance of content dissemination protocols. I-SEND focuses on non-safety applications in which the content dissemination is interest-driven and do not require all nodes forward each data packet.

I-SEND is evaluated by real trace-driven and synthetic simulations on the ONE (Opportunistic Network Environment) simulator under different scenarios. A novel metric referred to as *utility rate* and its variations quantify the gains of incorporating I-SEND in content dissemination for vehicular networks. The metric calculates the benefit of users by receiving the content (i.e. quantitative metric which indicates how much users are satisfied). The incorporation of I-SEND in the content dissemination is compared under the same scenarios with other forwarder selection approaches representative from the literature, as highest degree and enhanced highest degree, in which forwarders are selected based on degree centrality. Results have emphasized that the incorporation of I-SEND outperforms the use of compared schemes.

This paper proceeds as follows. Section II presents related works. Section III describes the I-SEND approach. Section IV details the performance evaluation methodology and results. Section V concludes the paper and highlights future works.

## II. RELATED WORK

Most of dissemination protocols are broadcast based. The simple flooding, Epidemic [2], is the most known dissemination protocol. It consists on retransmitting each message, when receiving it, to all neighbors. Based on broadcast dissemination, several vehicular network researches have investigated destination-driven content dissemination where they assume that destinations (i.e. consumers) are well defined. Those studies consider content dissemination protocols to distribute a single object. For destination-based dissemination, finding the proper forwarder to carry the content to the destination as quickly as possible is the important challenge. For example, a forwarder selection scheme is proposed in [3] which predicts

the vehicles mobility and selects the forwarder as the node that provides higher link reliability. Other social based data forwarding schemes [4], [5] consider various social network properties including betweenness centrality and communities in order to forward data to the prominent nodes. In [6], authors proposed ZOOM, a scheme to integrate both contact-level and social-level for fast opportunistic forwarding in vehicular networks. Knowing the predicted future contact and betweenness centrality, ZOOM enables to choose the next data-relay in order to minimize the end-to-end delay.

Differently from dissemination protocols that have specific destinations, this paper addresses interest-driven dissemination in order to distribute different content objects to as many users as possible. Moreover, this work considers heterogeneous user preferences enabling users to disseminate data based on their shared interests. In [7], authors presented the ROD protocol for infotainment application which disseminates data separately in each direction and optimizes data dissemination, in the intersection, in order to increase the delivery ratio. ROD enables to select the best relay node in each direction.

Most of the forwarder selection schemes consider a single object, ignoring user interests for different content objects. They target on speeding up the dissemination or increasing the delivery ratio, ignoring commuters desires. However, applications such as infotainment tempt to guarantee commuters comfort and to entertain them. Thus, there is an increasing demand for a successful dissemination scheme that considers user interests and aims to maximally satisfying user interests by choosing suitable forwarders which can produce higher utilities. I-SEND differs from the above forwarder selection schemes taking into account heterogeneous users interests and enables to maximize the benefits for users by choosing forwarders that can produce higher content utility.

### III. THE I-SEND APPROACH

This section describes the I-SEND (UtIlity-baSEd forwarder selection for coNtent Dissemination in vehicular networks) approach. Its overall goal lies in increasing content utility to end users in the context of non-safety applications, preserving the good performance of content dissemination protocols in vehicular networks. Next, an overview of the system model is presented, followed by the explanation of the I-SEND behavior and a motivational example.

#### A. System Model

Fig. 1 overviews the system model composed of two logical layers: *data propagation layer* and the *interest and content layer*. The former handles beacon exchange between pair of vehicles (nodes) representing the services of the physical, link and routing layers of the protocol stack; the latter provides information related to user interests and concentrates services from the transport and application layers.

From the *data propagation layer* perspective, the system involves a set of vehicles  $\mathcal{V} = \{V_i \mid i: \text{vehicle}' \text{ index}; i \in \mathbb{N}^*\}$  moving on the roads. Each vehicle  $V_i$  is equipped with a short-range wireless communication device, i.e. on board

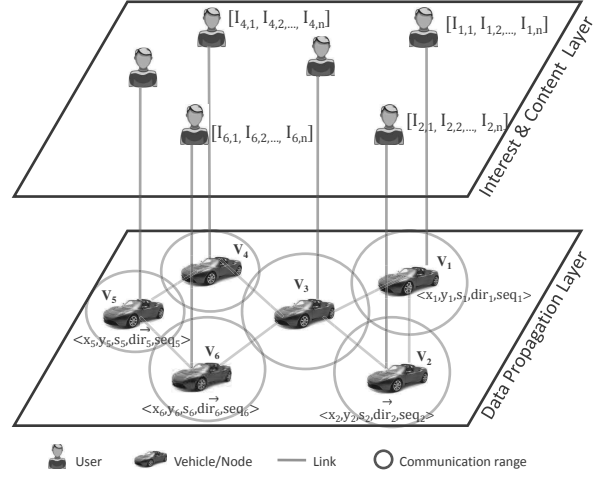


Fig. 1: System model overview

unit (OBU) or a smart-phone, to detect other users' devices and to communicate or share content. Vehicles share content using vehicle-to-vehicle (V2V) communications or vehicle-to-infrastructure (V2I), when this last exists. Selfishness is not considered, assuming that nodes will always cooperate.

Periodically, each vehicle aware of its neighboring nodes selects one of them as forwarder vehicle  $F_p$ . Hence,  $F_p$  is the responsible for diffusing the data to its neighbors. The set of all forwarder vehicles of the network is denoted by  $\mathcal{F} = \{F_p \mid p: \text{forwarder}' \text{ index}; p \in \mathbb{N}^*\}$ ,  $\mathcal{F} \subseteq \mathcal{V}$ . A local time synchronization is assumed between neighboring nodes, i.e. nodes in the communication range of others (see Fig. 1 – data propagation layer). There is no need for global time synchronization.

Let  $\mathcal{V}_{V_m}^t = \{V_i \mid V_i \text{ is neighbor of } V_m\}$  denote the neighbors of  $V_m$ , at time  $t$ , being  $\mathcal{V}_{V_m}^t \subseteq \mathcal{V}$ . Due to the high dynamism of vehicular networks topology, contact lifespan between a vehicle  $V_m$  and nodes in  $\mathcal{V}_{V_m}^t$  is very short and can be estimated based on the direction, speed, and velocity of the vehicles [8], [9]. Let us consider  $D_{i,m}$  the contact duration between a  $V_i \in \mathcal{V}_{V_m}^t$  and  $V_m$ . The value of contact lifespan between two nodes is expressed in terms of  $\Delta t$ , where  $\Delta t$  is assumed to be the time slot required to send/receive one content object. For instance,  $D_{i,m} = 3 \times \Delta t$  means that  $V_i$  can receive/send 3 objects from/to  $V_m$ .

Let  $\mathcal{V}_{V_m,k}^t = \{V_i \mid V_i \in \mathcal{V}_{V_m}^t; D_{i,m} = P_k\}$  denote the set of neighbors that are connected to  $V_m$  during a period  $P_k$ , where  $P_k = k \times \Delta t$  (e.g.  $D_{i,m} = P_3 \Leftrightarrow D_{i,m} = 3 \times \Delta t$ ),  $\mathcal{V}_{V_m,k}^t \subseteq \mathcal{V}_{V_m}^t$ . On the *interest and content layer*, each user is interested in a set of different predefined topics (e.g. traffic information, gas station offers, restaurant offers, and so on). Without loss of generality, this study assumes that each user is only associated to one vehicle and its interests do not change on a short timescale. Let  $\mathcal{T} = \{T_j \mid j: \text{topic index}; j \in \mathbb{N}^*\}$  denote the set of predefined topics and  $I_{i,j}$  denote the interest of a vehicle  $V_i$  in the topic  $T_j$ . Each node  $V_i$  owns at an instant  $t$  in its buffer a set of objects (i.e. shares of the content)  $\mathcal{O}_{V_i}^t = \{O_n \mid O_n \in \text{buffer of } V_i\}$ . Each object  $O_n$  of  $V_i$  is

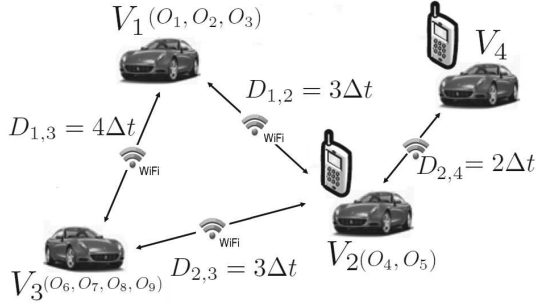


Fig. 2: Simple scenario for forwarder selection

related to a specific topic  $T_j$ , hence, the interest of a vehicle  $V_i$  for an object  $O_n$  is equal to the interest of  $V_i$  for  $T_j$ .

Let  $\mathcal{O}^t = \left\{ \bigcup O_n \mid \forall V_i \in \mathcal{V} \right\}$  denote the set of objects owned by all the  $V_i \in \mathcal{V}$  at an instant  $t$ . For the sake of simplicity and without loss of generality, this study assumes that all objects have an equal size. Table I summarizes the notations and definitions used.

Notation	Definition
$I_{i,j}$	Interest of vehicle $V_i$ in topic $T_j$ /object $O_n \in T_j$
$D_{i,m}$	Contact duration between vehicle $V_i$ and forwarder $V_m$
$P_k$	Contact duration in number of slots $\Delta t$
$\mathcal{V}_{V_m}^t$	Set of vehicles connected to $V_m$ at the instant $t$
$\mathcal{V}_{V_m,k}^t$	Set of vehicles connected to $V_m$ at the instant $t$ during the period of time $[t, t + P_k]$
$\mathcal{O}_{V_i}^t$	Set of objects owned by $V_i$ at the instant $t$

TABLE I: Notations used for I-SEND

Before proceeding, a simple example is provided, highlighting how the forwarder selection impacts the content utility.

**Motivating Example.** For the sake of illustration, Fig. 2 considers four vehicles  $V_1$ ,  $V_2$ ,  $V_3$ , and  $V_4$  that own the sets of objects  $(O_1, O_2, O_3)$ ,  $(O_4, O_5)$ ,  $(O_6, O_7, O_8, O_9)$ , and  $\emptyset$ , respectively. Each user has its interests (i.e. preferences) for the different objects as shown in Table II. At a given time  $t$ , these vehicles enter in contact. Let us consider  $D_{1,2}$ ,  $D_{2,3}$ ,  $D_{1,3}$ , and  $D_{2,4}$  the contact durations (CDs) between the connected vehicles expressed in terms of  $\Delta t$  as depicted in Fig. 2.

$V_1$	$O_1$	$O_2$	$O_3$	$V_2$	$O_4$	$O_5$	$V_3$	$O_6$	$O_7$	$O_8$	$O_9$
$V_2$	5	8	2	$V_1$	5	0	$V_1$	3	1	3	5
$V_3$	9	1	10	$V_3$	6	8	$V_2$	7	5	4	7
$\Sigma$	14	9	12	$V_4$	4	4	$\Sigma$	10	6	7	12
				$\Sigma$	15	12					

TABLE II: Example of simple scenario

For illustrating, let us assume a centrality-based forward selection scheme, in which the node with the highest degree (i.e. has the largest number of links) is selected as a forwarder. This scheme allows to maximize the number of messages sent since it chooses the most connected node as the forwarder. Thus, based on this scheme, the vehicle  $V_2$  will be the responsible for broadcasting its data to its neighbors, producing the utility:

$$U_{V_2} = (I_{1,4} + I_{3,4} + I_{4,4}) + (I_{1,5} + I_{3,5} + I_{4,5}) = 15 + 12 = 27$$

However, the forwarder sends to a maximum number of users, but unfortunately cannot achieve the maximal content utility. In particular, another scheme that consider heterogeneous user interests tends to maximally satisfy users. Knowing the neighbors' interests and contact lifespan, each node can compute the content utility that it can produce to its neighboring nodes. In order to produce the maximum content utility, vehicles  $V_1$ ,  $V_2$ , and  $V_3$  could schedule their objects as following  $[O_1, O_3, O_2]$ ,  $[O_4, O_5]$ , and  $[O_9, O_6, O_7, O_8]$ , respectively. Hence, the utility that can be produced by each vehicle is computed as the following:

$$U_{V_1} = (I_{2,1} + I_{3,1}) + (I_{2,3} + I_{3,3}) + (I_{2,2} + I_{3,2}) = 14 + 12 + 9 = 35$$

$$U_{V_2} = (I_{1,4} + I_{3,4} + I_{4,4}) + (I_{1,5} + I_{3,5} + I_{4,5}) = 15 + 12 = 27$$

$$U_{V_3} = (I_{1,9} + I_{2,9}) + (I_{1,6} + I_{2,6}) + (I_{1,7} + I_{2,7}) + I_{1,8} \\ = 12 + 10 + 6 + 3 = 31$$

In order to maximally satisfy users, a content utility based forwarder selection chooses the node which can produce the higher benefits to others.

$$F = V_i / U_{V_i} = \max \{U_{V_1}, U_{V_2}, U_{V_3}\} = V_1$$

Thus, node  $V_1$  will be selected as the forwarder since it is the vehicle that can achieve higher benefits for neighboring users comparing to vehicles  $V_2$  and  $V_3$ . Therefore, for a maximum utility contribution, an utility-based forwarder selection algorithm is more efficient than a centrality-based algorithm. However, nowadays users prefer to get few content matching more with their interests and bringing more benefits than receiving several content that they barely are interested in.

### B. Forwarder selection algorithm

Fig. 3 illustrates the behavior of the utility-based forwarder selection in four main steps: (i) receiving beacon messages, (ii) utility computation, (iii) forwarding objects or (iv) canceling. Periodically, nodes communicate by beacon messages which is useful for neighboring discovery and interests exchange. This information enables each node to compute the utility

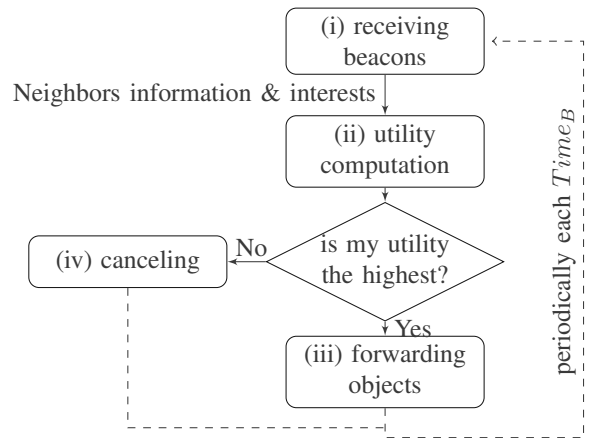


Fig. 3: Forwarder selection algorithm

that it can produce based on neighbors interests and contact lifespan. Then the node computes a backoff time which is inversely proportional to its utility and sets off a diffuse timer  $Time_D(U_{V_i})$ . If it receives other objects before  $Time_D(U_{V_i})$  expiration, the vehicle cancels its timer and acts as a receiver, otherwise it diffuses its content objects.

1) *Receiving beacon*: Beacon message contains the following information (see Fig. 1):

$$\langle x, y, s, \vec{dir}, seq \rangle$$

where  $(x, y)$  represents the current location of a given vehicle  $V_i$ ;  $s$  is its speed;  $\vec{dir}$  is a vector indicating the direction of the vehicle; and  $seq$  is a sequence of numbers describing  $I_{i,j}$ . For each  $V_i$ , the period of time between two beacon broadcasts is called *beacon refresh timer* ( $Time_B$ ). The beacon message conforms to the one in [10]. Since vehicles meet opportunistically and receive beacon messages,  $V_m$  is aware of its  $\mathcal{V}_{V_m}^t$ , being then informed about its neighbor's interests.

2) *Utility computation*: Each node has a view of its neighbors and their interests. Next steps present how each node  $V_m$  computes the amount of content utility it can produce to its neighbors. Utility computation is based on two main features: *contact lifespan* and *heterogeneous user interests* which are used for data scheduling.  $V_m$  selects the objects, as well as the order, they should be propagated. This process is updated each  $Time_B$  and follows four substeps that determine the  $N$  objects to be transmitted per interval.

**Substep 1:**  $V_m$  ignores the set of vehicles  $\mathcal{V}_{V_m,0}^t$ , i.e. neighboring nodes with who the contact duration is 0 (**zero**), since the communication between  $V_m$  and each node in  $\mathcal{V}_{V_m,0}^t$  is not maintained enough to exchange any object.  $\mathcal{V}_{V_m}^t$  is the list of vehicles connected to  $V_m$  that can receive at least one object.

$$\mathcal{V}_{V_m}^t = \bigcup_{k \neq 0} \mathcal{V}_{V_m,k}^t$$

**Substep 2:** As mentioned before, local time synchronization among neighbors is assumed, i.e. neighboring nodes schedule objects to be diffused at the same time. Even though, the synchronization is out of the scope of this paper, I-SEND may be adapted to the lack of synchronization. During  $Time_B$ , depending on the transmission rate and the content size,  $V_m$  can broadcast a maximum number of  $N$  objects. Thus,  $V_m$  can diffuse at most  $N$  objects during  $Time_B$  for its neighbors  $\mathcal{V}_{V_m}^t$ .  $V_m$  determines from  $\mathcal{O}_{V_m}^t$ , the  $N \leq |\mathcal{O}_{V_m}^t|$  most interesting objects for vehicles  $\mathcal{V}_{V_m}^t$ . Let  $U_{O_n}^t$  refers to the content utility by disseminating the object  $O_n$  during the period  $[t, t + Time_B]$ .

For  $O_n \in \mathcal{O}_{V_m}^t$

$$U_{O_n}^t = \sum_{V_i \in \mathcal{V}_{V_m}^t, O_n \notin \mathcal{O}_{V_i}^t} I_{i,j}$$

The list of objects that can be broadcasted by  $V_m$  is  $\mathcal{O}_{V_m}^{*t} = [O_1^*, O_2^*, \dots, O_N^*]$ . It is given by the following computation:

$$O_1^* = O_n \in \mathcal{O}_{V_m}^t / U_{O_n}^t = \max_{O_k \in \mathcal{O}_{V_m}^t} U_{O_k}^t$$

for  $i$  from 2 to  $N$

$$O_i^* = O_n \in \mathcal{O}_{V_m}^t \setminus \{O_1^*, O_2^*, \dots, O_{i-1}^*\} / U_{O_n}^t = \max_{O_k \in \mathcal{O}_{V_m}^t} U_{O_k}^t$$

Therefore,  $V_m$  determines the set of objects that can be distributed in the period  $[t, t + Time_B]$ , which is:

$$\mathcal{O}_{V_m}^{*t} = [O_1^*, O_2^*, \dots, O_N^*]$$

**Substep 3:** After selecting the  $N$  objects to send,  $V_m$  sorts them as follows. Assuming that the content utility is not affected when the user receives, during  $Time_B$ , a set of objects in different order, e.g. a user gets the same utility if it receives two objects  $O_1$  and  $O_2$  in this order  $[O_1, O_2]$  or  $[O_2, O_1]$  during  $[t, t + 2\Delta t]$ . Hence, to order the  $N$  selected objects,  $V_m$  ignores the set  $\mathcal{V}_{V_m,N}^t$  since they can receive all the  $N$  objects that  $V_m$  can diffuse in the period  $[t, t + Time_B]$ .

For all  $V_i \in \mathcal{V}_{V_m,k}^t$ , the order for the  $k$ -first objects does not matter since they will receive all the  $k$ -first objects. However, this order has an impact on the content utility for the sets  $\mathcal{V}_{V_m,1}^t, \mathcal{V}_{V_m,2}^t, \dots, \mathcal{V}_{V_m,k-1}^t$ . For instance, nodes in the set  $\mathcal{V}_{V_m,k-1}^t$  prefer the  $(k-1)$  most important objects first and the less important objects to be sent in the end. Being  $O_i^f$  the selected object to be sent in the  $i^{th}$  position, the final objects schedule is calculated as following:

$$\text{Let us denote } U_{O_n, P \leq P_k}^t = \sum_{V_i \in \bigcup_{0 < z \leq k} \mathcal{V}_{V_m,z}^t, O_n \notin \mathcal{O}_{V_i}^t} I_{i,j}$$

$$O_N^f = O_n \in \mathcal{O}_{V_m}^{*t} / U_{O_n}^t = \min_{k \in [1, N]} U_{O_k, P \leq P_{N-1}}^t$$

$$= \min_{k \in [1, N]} \sum_{V_i \in \mathcal{V}_{V_m}^{*t} \setminus \mathcal{V}_{V_m,N}^t, O_n \notin \mathcal{O}_{V_i}^t} I_{i,j}$$

for  $i$  from  $(N-1)$  down to 1

$$O_i^f = O_n \in \mathcal{O}_{V_m}^{*t} \setminus \{O_N^f, \dots, O_{i+1}^f\} / U_{O_n}^t = \min_{k \in [1, N]} U_{O_k, P \leq P_{i-1}}^t$$

Thus, to maximize the utility that can be produced,  $V_m$  schedules its objects in this order:

$$\mathcal{O}_{V_m}^{ft} = [O_1^f, O_2^f, \dots, O_N^f]$$

**Substep 4:** After  $V_m$  scheduled its objects, it computes the content utility that it can produce to its neighborhood. Let  $I_{i,z}^f$  denote the interest of vehicle  $V_i$  to the content object  $O_z^f$  (i.e.  $I_{i,z}^f = I_{i,j}$  if  $O_z^f = O_j$ ). Let  $U_{V_m}^t$  refers to the content utility that can be produced by  $V_m$  disseminating its scheduled objects  $\mathcal{O}_{V_m}^{ft}$  to its neighbors  $\mathcal{V}_{V_m}^{*t}$  during the period  $[t, t + Time_B]$ .

$$U_{V_m}^t = \sum_{z=1}^{\frac{D_{i,m}}{\Delta t}} \sum_{V_i \in \mathcal{V}_{V_m}^{*t}, O_z^f \notin \mathcal{O}_{V_i}^t} I_{i,z}^f$$

3) *Forwarder selection and objects propagation*: After each node computes its content utility for neighbors, one from the neighboring nodes will be selected as the forwarder  $F_p$  which is the node that can produce maximum utility. To do so, each node  $V_i$  computes a backoff time that is inversely proportional to its utility and sets off a sending timer  $Time_D(U_{V_i})$ . If the node receives objects before the timer expiration, then it acts as receiver; otherwise, it becomes a forwarder  $F_p$  and it broadcasts its data.

$$F_p = V_m / U_{V_m}^t = \max_{V_i \in \mathcal{V}_{V_m}^t} U_{V_i}^t$$

#### IV. PERFORMANCE EVALUATION

Trace-driven and synthetic simulations are conducted using the Opportunistic Network Environment (ONE) simulator [11]. Trace-driven scenarios employ trace collection of 100 taxi cabs randomly chosen [12], whereas in synthetic scenarios vehicles follow the vehicular-based map-driven model [13] which is part of the ONE simulator. Trace-driven and synthetic scenarios consider 100 equipped vehicles, each one with a transmission range of 200 m and the transmission speed of 6 Mbps. 1000 objects with equal size 1 Mb are generated at the beginning of each simulation and distributed uniformly among 10 users as initial data sources. For each user/node, a list of interests for the different objects is selected randomly, following a uniform distribution.

Evaluations employs different levels of parameters, as buffer sizes (100~700 objects), Time-To-Live TTLs (10~80 min), and object size (1~3 Mb). For synthetic scenarios, vehicles move with speeds from 60 km/h to 120 km/h in the area of  $8500 m \times 6000 m$ . Plots present the mean values, with 95% confidence interval, of 10 simulations for each scenario, using different random seeds. Confidence interval values are below  $1.27 \times 10^{-4}$ , hence they are not shown in plots. In the literature [10], [14], [15], different values of  $Time_B$  are used in the range  $[3s, 5s]$ . In this study,  $Time_B$  is set to 4 s.

Plots compare results from I-SEND with the two following forwarder selection schemes. These schemes have been chosen because results presented in several works points out that centrality is the primary factor giving the best performance tradeoff [16].

- 1) **Highest Degree** - the node with higher centrality [5] (i.e. high number of links) is selected as forwarder. This forwarder is considered as the node playing a vital role comparing to others. Thus, it enables to send messages for as many users as possible.
- 2) **Enhanced-Highest Degree** - this is an enhanced version of highest degree. After selecting the forwarder as the node with the highest centrality, it enables the forwarder to efficiently schedule its data using the substeps 1, 2, and 3 of Section III-B in order to maximize the utility of its neighborhood.

Evaluations employ *content utility rate*, and its variations, as metric to compare the performance of I-SEND with the above

mentioned schemes. The utility rate is calculated as follows:

$$\text{Content Utility rate (U)} = \frac{\sum_{V_i, O_n \in \mathcal{O}_{V_i}^t} I_{i,j}}{\sum_{V_i, O_n} I_{i,j}}$$

#### A. Results

Fig. 4 and Fig. 5 show the mean of content utility rate produced in the network over time using the synthetic mobility model and real traces, respectively. All nodes have enough memory capacity to store all the objects in the network, and the objects have long enough lifetime to be received by all nodes in the scenarios. Thus, simulations run until each node receives all objects in the network. Both figures show that I-SEND can produce higher utility than both Highest-degree and Enhanced Highest-degree schemes. With the mobility mode, Fig. 4 shows that at the instant 3375s, I-SEND produced 92.7% of utility while Enhanced Highest-degree and Highest-degree produced 87.6% and 78.7% respectively. Otherwise, to obtain a 92.7% utility for users, I-SEND, Enhanced Highest-degree and Highest-degree require 3375, 3912, and 4525 seconds. With real trace, Fig. 5 shows that I-SEND produced 82.5% of utility while Enhanced Highest-degree and Highest-degree produced 76.7% and 68% respectively.

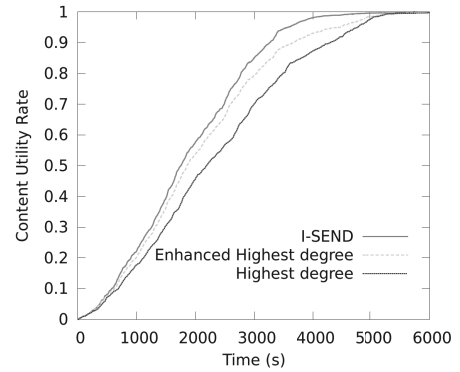


Fig. 4: Synthetic scenario: cumulative utility rate over time

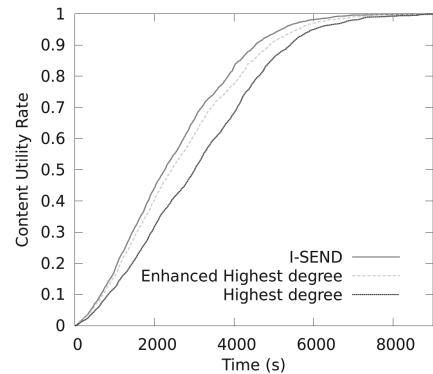


Fig. 5: Trace-driven scenario: cumulative utility rate over time

The improvement shown in Fig. 4 and Fig. 5 is mainly because that, in I-SEND, the forwarder is chosen based on the importance of the objects in its buffer, which in turn is related to its contact lifespan to its neighbors. Therefore, a forwarder is selected in order to maximize the benefit for its

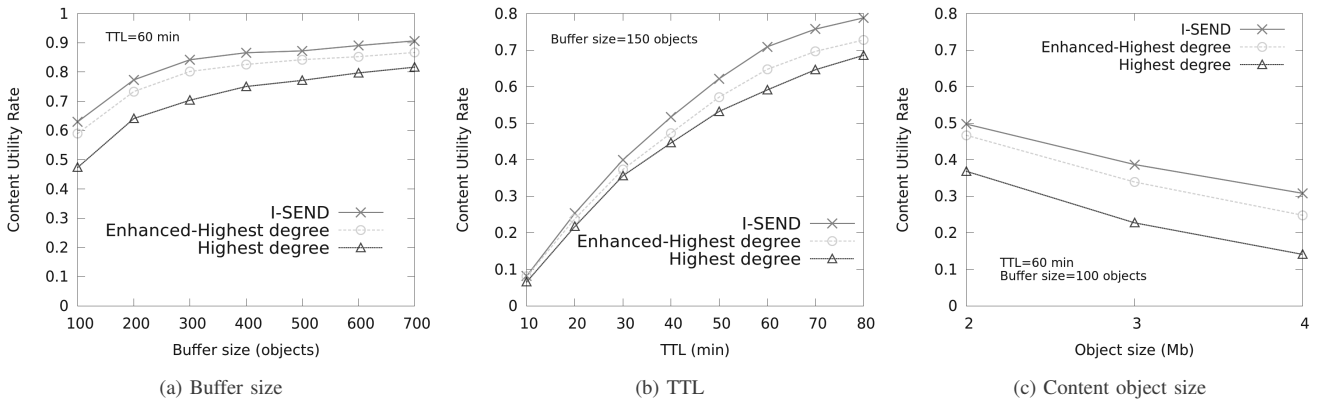


Fig. 6: Cumulative utility with respect to buffer size, TTL, and content object size

neighboring users instead of a forwarder that can diffuse its objects to many neighboring nodes. Some objects can provide low benefits even if they are diffused to many users.

Next figures intend to show how I-SEND performs in different environment varying buffer size, object TTL, and object size. Fig. 6a demonstrates the impact of the object size on the utility rate. The figure shows that the advantage of I-SEND compared to Highest-degree increases when the buffer size decreases. This is because with small buffer size and limited TTL, a forwarder needs to broadcast the set of objects that can benefit its neighborhood the most in limited contact duration. Having a limited buffer size, Fig. 6b shows the improvement of I-SEND under TTL variations. For limited TTL and buffer size, the probability that the user receives the objects in which the user is interested before their lifetime expires decreases. This happens due to limitation in lifetime, buffer size and duration of contact. Hence, it becomes more important to select a forwarder that can send the appropriate set of objects in the short contact duration in order to produce as much utility as possible. Fig. 6c shows the improvement achieved by I-SEND when the object size grows up. Larger object size requires a longer transmission time. Hence, selecting the forwarder that owns the set of objects that can benefit the others the most in a limited period of time is required.

## V. CONCLUSION

This paper presented I-SEND, a forwarder selection scheme for non-safety and interest-driven applications in vehicular networks. The content utility, i.e. the benefit that users can have in receiving a content, provided by forwarder candidates leads the selection. Differently from other schemes, periodically each vehicle calculates the content utility of each neighboring node based on the neighbor interests and contact lifespan. The neighboring node that can produce the highest content utility at a time is chosen as forwarder since it can maximize users satisfaction. Trace-driven and synthetic simulation results demonstrated the efficiency of the I-SEND scheme under different levels of buffer size, TTL and object size. As future work, it is expected to adaptively aggregate different criteria in the forwarder selection and take into account social selfishness.

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