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# SCARF: A SoCial-Aware Reliable Forwarding Technique for Vehicular Communications

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The Internet-of-Vehicles allows the coexistence of traditional Internet applications with the Internet-of-Things, so that vehicles can communicate not only among them but also to neighboring devices and humans as well. In this context, the human social behavior is a fundamental aspect that needs to be taken into account specially for message dissemination in Vehicular Social Networks.

In this paper, we present a probabilistic broadcast protocol that exploits the “social degree” of a vehicle to be selected as next-hop forwarder. The social degree of a vehicle depends on its social activity inside a vehicular social network, so that a vehicle that uses to access and post often in a given vehicular social network is more likely to be “socially trusted”. Selecting a trusted vehicle as next-hop forwarder allows a secure and faster message dissemination with respect to an “asocial” vehicle. Simulation results show that a socially trusted vehicle improves network performance, expressed in terms of overall throughput.

Additional Key Words and Phrases: Vehicular Social Networks, social degree, forwarding probability, collision probability

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## 1 INTRODUCTION

Nowadays, many vehicular applications are emerging, arising mainly from road safety and then to entertainment. The concept of Internet-of-Vehicles (IoV) [?] is then proliferating, and it is an inevitable convergence of the existing mobile Internet and the concept of Internet-of-Things (IoT). In IoV, Internet applications go on “wheels”, then converting the existing vehicles into “digital cars” equipped with several technologies and sensors [?].

Moving from the existing concept of Vehicular Ad-hoc Networks (VANETs) [?] that allow opportunistic vehicular communications among vehicles *i.e.*, vehicle-to-vehicle (V2V), and from vehicles to infrastructure *i.e.*, vehicle-to-infrastructure (V2I), IoV technology refers to dynamic mobile communication systems that extend the concept of vehicular communications to vehicle-to-human (V2H) and vehicle-to-sensor (V2S) interactions. It enables information sharing and the gathering of information on vehicles, roads and their surrounds.

In IoV, the V2H interactions are governed by user behavior and needs. For instance, a user can book a ride to an unmanned taxi based on her needs and daily mobility. Then, understanding user behavior and mobility patterns is fundamental in the design of efficient communication systems in IoV. Also, real-life interactions among users have a direct impact on the performance of the network.

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53 The dependence of mobility on social interactions has been a topic of interest of many researchers in the last years.  
54 Some of the first papers focusing on the strict relation between mobility model and social network theory has been  
55 investigated in [?]. Musolesi and Mascolo [?] propose a new mobility model where the input of the model is the social  
56 network of the individuals carrying the mobile devices. By analyzing the results, the authors derive that the movements  
57 of the handheld users are also driven by the social relationships of the individuals. This dependence has also been  
58 investigated by Cho *et al.* in [?]. The authors state that the short-ranged travel is less impacted by the social network  
59 structure, while if a person travels a long distance then they are more likely to travel near an existing friend.  
60

61  
62 The meeting of mobility with social interactions rises to a particular class of social networks, namely the Vehicular  
63 Social Networks (VSNs) [?]. VSNs are online social networks where the social interactions are built *on-the-fly*, due to  
64 the opportunistic links in vehicular networks. They exploit mobility aspects and basics of traditional social networks, in  
65 order to create novel approaches of message exchange through the detection of dynamic social structures. For instance,  
66 a VSN can exist based on driver's daily mobility *i.e.*, moving every day from home to office. During the journey, the  
67 vehicle can access different social networks like (i) the network with members talking about traffic information *i.e.*,  
68 content-based social network, (ii) the network of a particular area of interest *i.e.*, position-based social network, and (iii)  
69 the network with members belonging to the same office *i.e.*, relationship-based social network. Then, we can figure out  
70 that a vehicular social network is stronger impacted by short-ranged daily travels, than by long-ranged travels.  
71

72  
73 How social interactions affect message dissemination represents an important topic of interest for many researchers  
74 in the VSN context. Forwarding techniques in VSNs should not only consider existing constraints in vehicular ad hoc  
75 networks (*i.e.*, mobility, and connectivity issues), but also social aspects (*i.e.*, messages are forwarded among trusted  
76 users, which are sharing same interests and move in a common place at the same time). As known, traditional forwarding  
77 techniques in VANETs are based on physical parameters, like the inter-vehicle distance so that the larger the distance  
78 is, higher will be the forwarding probability [?]. Similar approaches based on this criterion have been presented, like  
79 the Irresponsible Forwarding protocol which aims to limit the number of rebroadcasts [?]. However, when considering  
80 VSNs where nodes share common interests with other neighboring vehicles, message forwarding techniques should  
81 consider user social behavior and mobility pattern. For example, in [?] Herrera-Tapia *et al.* introduce a Friendly-Sharing  
82 diffusion approach based on the consideration that the number of messages shared among nodes is improved when the  
83 contact duration is increased.  
84

85  
86 In this paper, we present a probabilistic broadcast protocol based on the social activity of a vehicle in a vehicular  
87 social network. The proposed technique is named *SoCial-Aware Reliable Forwarding (SCARF)*, which selects a next-hop  
88 vehicle according to its social parameter *i.e.*, how much a vehicle is socially trusted inside a vehicular social network.  
89 Indeed, like in traditional online social networks like Facebook or Instagram, in a vehicular social network not all the  
90 vehicles are "social", but it depends on the own social activity. For instance, a vehicle that uses to access a vehicular  
91 social network and posts comments every day on its own path from home to office is likely assumed to be a "social"  
92 vehicle, while a vehicle that sporadically connects to a vehicular social network and does not use to post is likely an  
93 "asocial" vehicle. Then, we can distinguish social vehicles inside a vehicular social network if their *social (activity) degree*  
94 is higher than a given threshold.  
95

96  
97 Packet transmission via SCARF occurs on the basis of a probabilistic analysis *i.e.*, the probability that a social vehicle  
98 will forward a packet. The selection of a social vehicle as next-hop message forwarder is expected to affect network  
99 performances. Indeed, by comparing a social vehicle to an asocial one, we notice that due to its high social degree the  
100 former can forward a message with a higher probability with respect to an asocial vehicle. As a result, by selecting  
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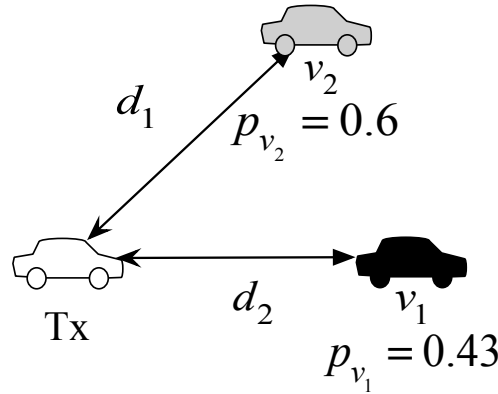


Fig. 1. Schematic of the SCARF technique. At the same distance from a transmitter vehicle (*i.e.*,  $d_1 = d_2$ ), each potential forwarding vehicle can have a different social parameter, which corresponds to a different forwarding probability (*i.e.*,  $p_{v_1} \neq p_{v_2}$ ).

social vehicles as potential forwarders we expect a more reliable message dissemination mechanism. This also allows secure communications, since a social vehicle is assumed to be a trusted vehicle. Finally, in order to provide an effective packet transmission with no packet collisions, the SCARF protocol also supports a collision detection mechanism.

This paper is organized as follows. Section 2 describes the mathematical model of SCARF approach, by distinguishing the forwarding probability and the collision probability. In Section 3 we report and discuss the simulation results related to SCARF technique. Finally, conclusions are drawn at the end of this paper.

## 2 PROPOSED TECHNIQUE

SCARF provides message rebroadcasting only to selected vehicles showing a social degree that makes them socially trusted. Indeed, SCARF's main goal is to identify trusted vehicles that can forward messages in a fast and reliable manner, thus allowing a high message dissemination rate within a VSN. This can be achieved while guaranteeing a reduced collision probability. Thus, SCARF relies on two aspects *i.e.*, the *social-based reliable forwarding* and the *collision probability*, respectively investigated in the following Subsection 2.1 and 2.2.

### 2.1 Social-based reliable forwarding

Our proposed technique is based on a social-based forwarding probability  $p_f$ , so that a vehicle that receives a packet should rebroadcast it only to the  $i$ -th "trusted" vehicle in its transmission range that has the following probability, *i.e.*:

$$p_{f,i} = \exp \left[ -\frac{\rho(z - d_i)}{c \cdot S_i} \right], \quad (1)$$

where  $d_i$  [m] is the inter-vehicle distance between the  $i$ -th receiving vehicle and the transmitting vehicle,  $\rho$  [veh/m] is the exponentially distributed inter-vehicle spacing with mean value  $1/\rho$ ,  $c \leq 1$  is a shape coefficient, and  $S_i \leq 1$  is the social parameter of the  $i$ -th vehicle.

A trusted vehicle is a vehicle that shows an appropriate social behavior with respect to a given VSN. For instance, a vehicle that accesses a VSN every day and has a high social activity degree (*e.g.*, it posts several comments in the VSN) can be awarded as "socially trusted vehicle". Mathematically, the social behavior of the  $i$ -th vehicle is expressed in

terms of its social parameter  $S_i$  ranging from 0 (*i.e.*, the vehicle has no social behavior and then it is not socially trusted) to 1 (*i.e.*, the vehicle has a social behavior, and then it is socially trusted). The social parameter takes into account the social degree of a vehicle in a given VSN, and it depends on (i) the degree of activity of a vehicle in a social network (*i.e.*, computed through the average number of posts and the number of accesses made), and (ii) the degree of correlation of the social behavior with respect to the mobility pattern.

Mathematically, we can define the social parameter as the probability that a vehicle is “socially active” in a VSN, assuming it is interested in the content discussed among members in the social network. For instance, let us assume two hypothesis (*i.e.*,  $H_1$  and  $H_2$ ) respectively that (i) a vehicle is interested in the relevant content of a given VSN (namely,  $VSN_1$ ), and (ii) a vehicle is interested in another VSN (namely,  $VSN_2$ ). Then, under the hypothesis  $H_1$ , the social parameter  $S_i$  of the  $i$ -th vehicle is expressed as:

$$S_{i,H_1} = \Pr \left\{ a_{i,H_1} > A \mid H_1 \right\}, \quad (2)$$

where  $a_{i,H_1}$  is the degree of social activity of the  $i$ -th vehicle depending on the average number of posts published in  $VSN_1$  (*i.e.*,  $n_{p,H_1}$ ) and the average number of accesses in  $VSN_1$  (*i.e.*,  $n_{a,H_1}$ ), *i.e.*

$$a_{i,H_1} = \frac{n_{p,H_1}}{n_{a,H_1}}. \quad (3)$$

In (2) the term  $A$  represents a threshold that determines if a vehicle has higher degree of social activity (*i.e.*, if  $a_{i,H_1} > A$  or not).

Figure 1 depicts the schematic of the SCARF technique. Let us consider a source vehicle (*i.e.*, Tx vehicle) is transmitting a message towards a next-hop vehicle inside its transmission range. Different vehicles can be eligible as next-hop forwarder, based on both physical metrics (*i.e.*, the distance from the transmitter) and also on social parameters. Assuming two vehicles (*i.e.*,  $v_1$  and  $v_2$ ) are at the same distance from the transmitter vehicle (*i.e.*,  $d_1 = d_2 = 150$  m), and that the degree of (social) activity in  $VSN_1$  is  $a_{1,H_1} = 0.5$  and  $a_{2,H_1} = 0.01$  for  $v_1$  and  $v_2$ , respectively, then a message will be forwarded to that vehicle having higher forwarding probability. Specifically, the probability of forwarding for  $v_1$  is  $p_{v_1} = 0.43$ , while for  $v_2$  it is  $p_{v_2} = 0.6$ . Vehicle  $v_2$  will be elected as socially-trusted vehicle, and then selected as next-hop forwarder.

It follows that by using the Bayes theorem, (2) becomes:

$$S_{i,H_1} = \frac{p_1 a_{i,H_1}}{p_1 a_{i,H_1} + p_2 a_{i,H_2}}, \quad (4)$$

where  $p_1$  and  $p_2$  are the probabilities that a vehicle is in the hypothesis  $H_1$  and  $H_2$ , respectively. In (4), we consider  $a_{i,H_1} \neq a_{i,H_2}$ . Figure 2 depicts the probability of having a social trusted vehicle to whom forward a packet. The vehicle is assumed to be connected in a given VSN (*i.e.*,  $VSN_1$ ) that represents the scenario of hypothesis  $H_1$ . The vehicle is then considered as socially trusted if the probability (4) is higher than a given threshold (*e.g.*,  $> 0.7$ ). This occurs for different values of  $a_{H_1}$  and  $a_{H_2}$ . For instance, according to Figure 2 for  $a_{H_1} = 0.2$  only the vehicle showing the lowest degree of activity in  $H_2$  (*i.e.*,  $a_{H_2} = 0.01$ ) is considered as a social vehicle since its social parameter<sup>1</sup> is higher than 0.7. Literally speaking,  $a_{H_2} = 0.01$  means that the degree of activity in  $VSN_2$  is very low and the vehicle is not socially-trusted in  $VSN_2$ . As a consequence, for  $a_{H_2} = 0.01$  it is expected that the behavior of the vehicle in  $VSN_1$  will be higher and then, the probability that it is a socially-trusted vehicle in  $VSN_1$  will be higher.

<sup>1</sup>Notice that from (2) the social parameter represents a probability, and so the terms “probability of social vehicle” and “social parameter” of the  $i$ -th vehicle are given interchangeably in this paper.

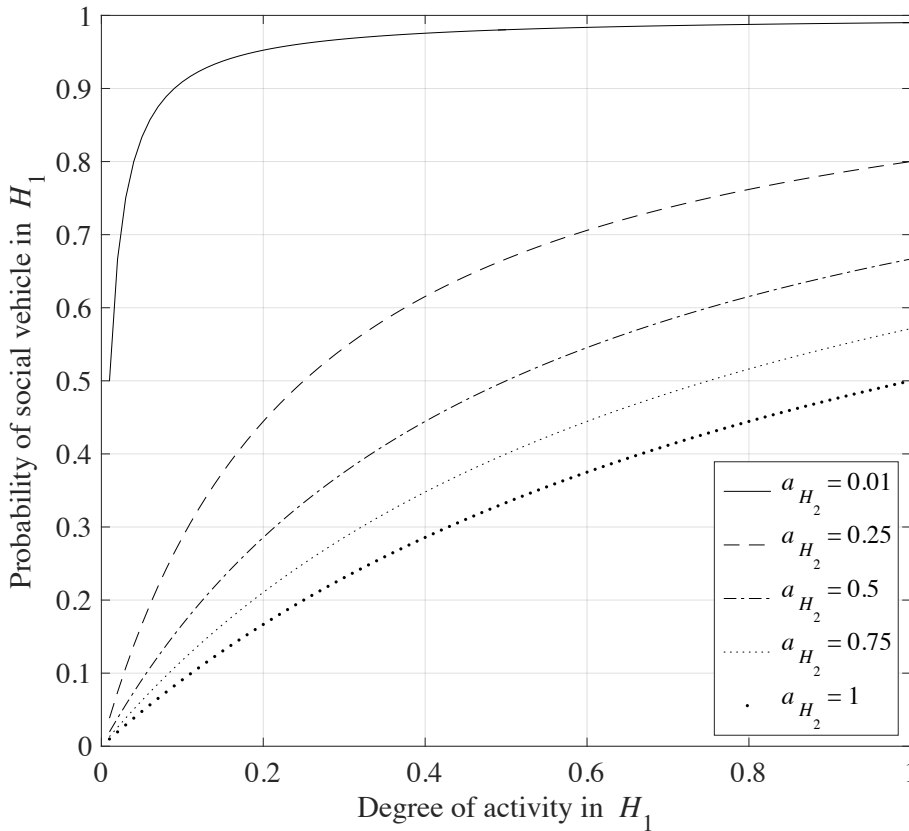


Fig. 2. Probability of social-trusted vehicle versus the degree of activity under the hypothesis  $H_1$ , for different values of the degree of activity in  $H_2$ .

The social-based forwarding probability expressed in Eq. (1) is plotted in Figure 3 versus the degree of activity in hypothesis  $H_1$  (*i.e.*,  $a_{H_1} = [0, 1]$ ) and for different values of inter-vehicle distance (*i.e.*,  $d = [50, 150, 190]$  m) within the transmission range of the source vehicle (*i.e.*,  $d < 200$  m), and of the degree of activity in hypothesis  $H_2$  (*i.e.*,  $a_{H_2} = [0.01, 0.25, 0.5, 0.75, 1]$ ). As previously said, the SCARF probability derives from traditional forwarding probabilistic techniques applied to vehicular communications, and then it depends on the inter-vehicle distance, so that the farther the forwarder from the source vehicle is, the higher the forwarding probability is. Thus, we observe that for increasing distances the forwarding probability increases as well (see the red curves in Figure 3). However, the social feature is taken into account so that for a fixed distance not all the vehicles are potentially eligible as next-hop forwarder, but it depends on the degree of social activity in  $H_1$  and  $H_2$ .

Finally, in Figure 4 we show the social-based forwarding probability of a vehicle versus the inter-vehicle distance inside the transmission range, for different values of the degree of activity in hypothesis  $H_2$ . We notice that the forwarding probability increases for high values of the distance, and also for high values of the activity degree  $a_{H_2}$ . This is due since the farthest the vehicle is in a transmission range, the highest the forwarding probability is; and also, the lowest the degree of activity in  $H_2$  is, the highest the forwarding probability is. For instance, if a potential next-hop

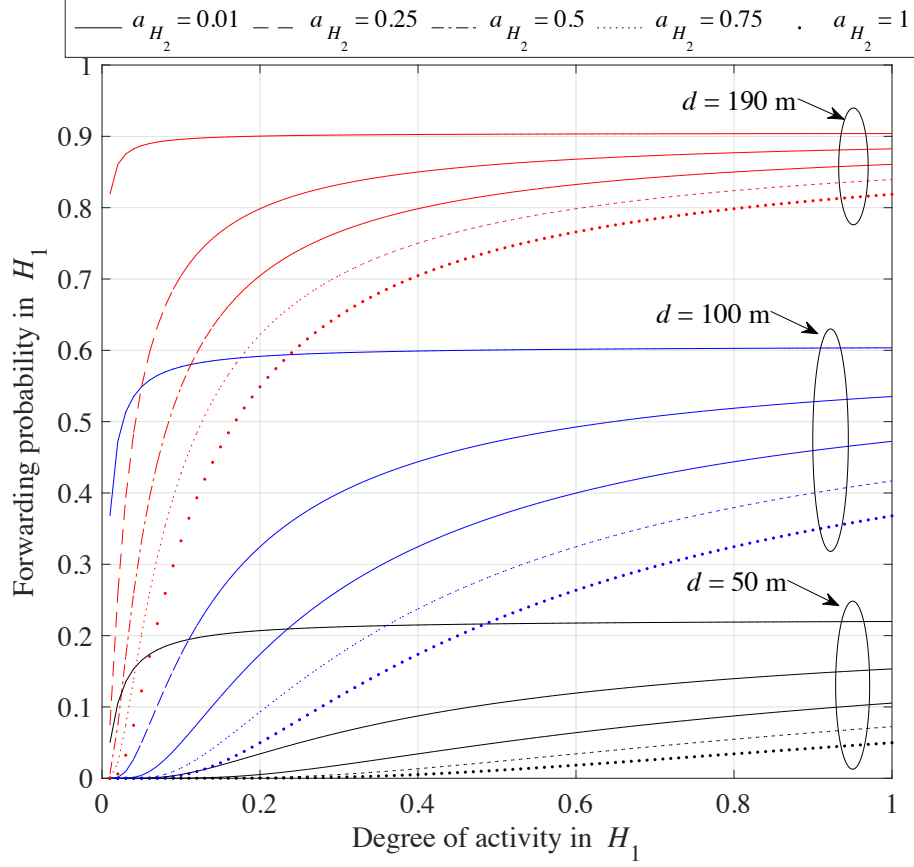


Fig. 3. Probability of social-based forwarding versus the degree of activity under the hypothesis  $H_1$ , for different values of inter-vehicle distance (i.e.,  $d < z$  and  $z = 200$  m) and degree of activity in  $H_2$ .

vehicle lays at 150 m from a source vehicle, based on the degree of activity in  $H_2$ , the forwarding probability will change accordingly (e.g.,  $p_f = 0.31$  for  $a_{H_2} = 1$ , and  $p_f = 0.6$  for  $a_{H_2} = 0.01$ ).

## 2.2 Collision probability

The collision probability is the probability that at least two or more vehicles start transmitting at the same time. This can be defined as

$$P_{coll} = P_{busy}(1 - P_t), \quad (5)$$

where  $P_{busy}$  is the busy probability that at least one vehicle (i.e., the  $i$ -th vehicle) is using the channel at the same time slot i.e.,

$$P_{busy} = 1 - (1 - p_{f,i})^{(n-1)}, \quad (6)$$

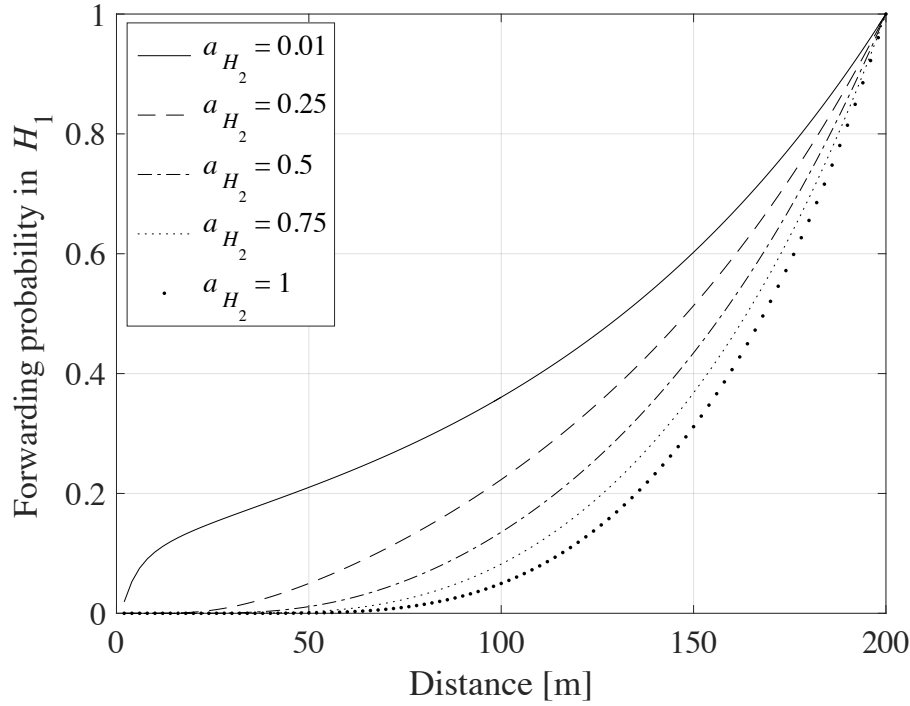


Fig. 4. Probability of social-based forwarding versus the inter-vehicle distance (*i.e.*,  $d < z$  and  $z = 200$  m) under the hypothesis  $H_1$ , for different values of degree of activity in  $H_2$ .

and  $P_t$  is the probability that only one vehicle (*i.e.*, the  $i$ -th vehicle) is using the channel *i.e.*,

$$P_{t,i} = \frac{p_{f,i} (1 - p_{f,i})^{(n-1)}}{P_{busy}}, \quad (7)$$

where  $n$  is the number of interfering vehicles.

The trend of the collision probability is depicted in Figure 5 versus the inter-vehicle distance (*i.e.*,  $d \leq 200$ ) for different number of interfering vehicles (*i.e.*,  $n = [2, 5, 10]$ ) and the degree of activity in hypothesis  $H_2$ . As expected, we observe that higher the number of interfering vehicles is, higher is the collision probability, as well as larger the next-hop transmission range, higher the collision probability. Interesting we notice that for higher degree of activity in hypothesis  $H_2$ , the collision probability is lower since in this case the forwarding probability is lower as well. However, we observe that for a lower degree of activity (*e.g.*, see the solid red line for  $a_{H_2} = 0.01$  and  $n = 10$ ) small increases of the distances correspond to very high values of collision probability. For instance, we get  $P_{coll} = 0.143$  for  $d = 2$  m and  $P_{coll} = 0.354$  for  $d = 4$  m. As a remark, we observe that the collision probability changes the shape for small distances (*i.e.*,  $< 50$  m) and increasing interfering vehicles (*i.e.*, solid red and blue curves), while for lower interferes this does not occur (see solid black line). This is expected since the scenario with high interfering vehicles in small distances represents a likely collision event.



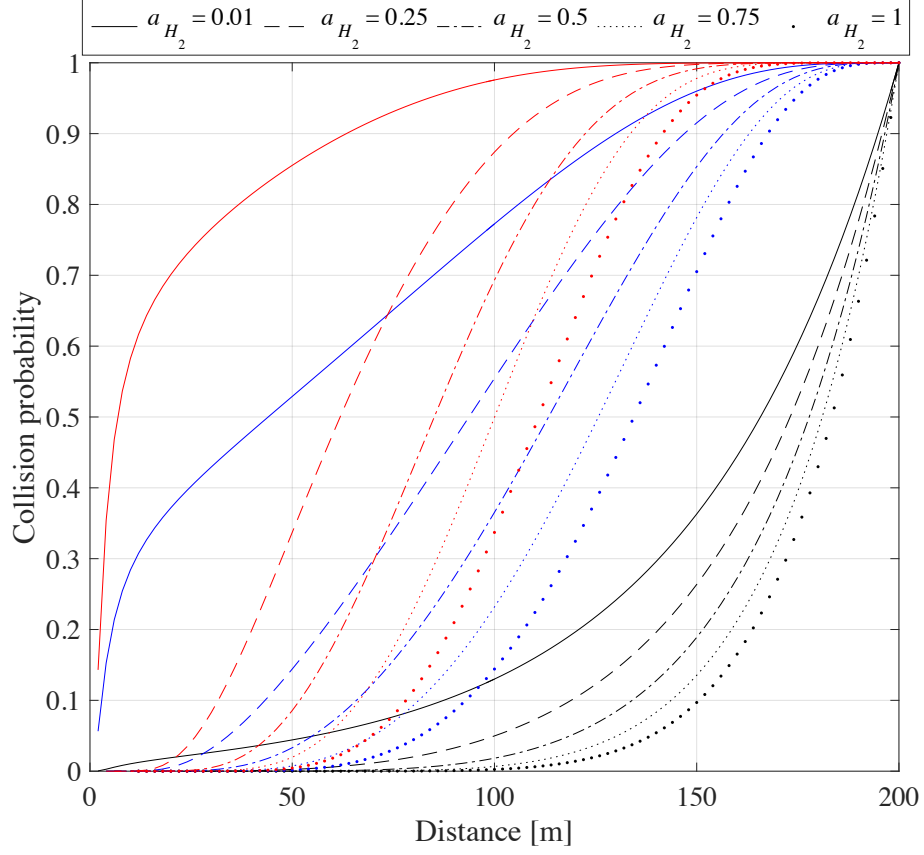


Fig. 5. Collision probability versus the inter-vehicle distance (*i.e.*,  $d \leq z$  and  $z = 200$  m) under the hypothesis  $H_1$ , for different values of interfering vehicles with this transmission range (*i.e.*,  $n = [2, 5, 10]$  for *black*, *blue*, and *red* curves, respectively) and the degree of activity in  $H_2$ .

By fixing a threshold for the collision probability, the next forwarding vehicle will be all those vehicles experiencing lower values for the collision probability. The collision threshold detects the maximum allowed distance from the source where a vehicle experiences the collision threshold. It varies according to VANETs factors, such as the inter-vehicle distance (*i.e.*,  $d$  [m]) and the vehicular density (*i.e.*,  $\rho$  [veh/m]), as well as the social factor *i.e.*, the degree of activity in hypothesis  $H_2$ . It is expressed as:

$$Th_{coll} = 1 - \exp\left(-\frac{\rho \cdot d}{a_{H_2}}\right). \quad (8)$$

Figure 6 depicts the dynamic trend of collision threshold versus the inter-vehicle distance for different degrees of activity. As expected, for a fixed distance, the collision threshold increases for decreasing degree of activity in  $H_2$ . Indeed, as depicted in Figure 4, for lower values of  $a_{H_2}$  the probability of forwarding will be likely higher than the case of higher values of  $a_{H_2}$ . It follows that the collision threshold is expected to be higher for lower degree of activity in  $H_2$ , and vice versa. In Figure 6 we highlight two areas through a blue and a green rectangle, respectively indicating an area with  $Th_{coll} \leq 0.4$  and  $Th_{coll} \leq 0.5$ . In the first case (*blue rectangle*) the collision threshold is reached for a vehicle with

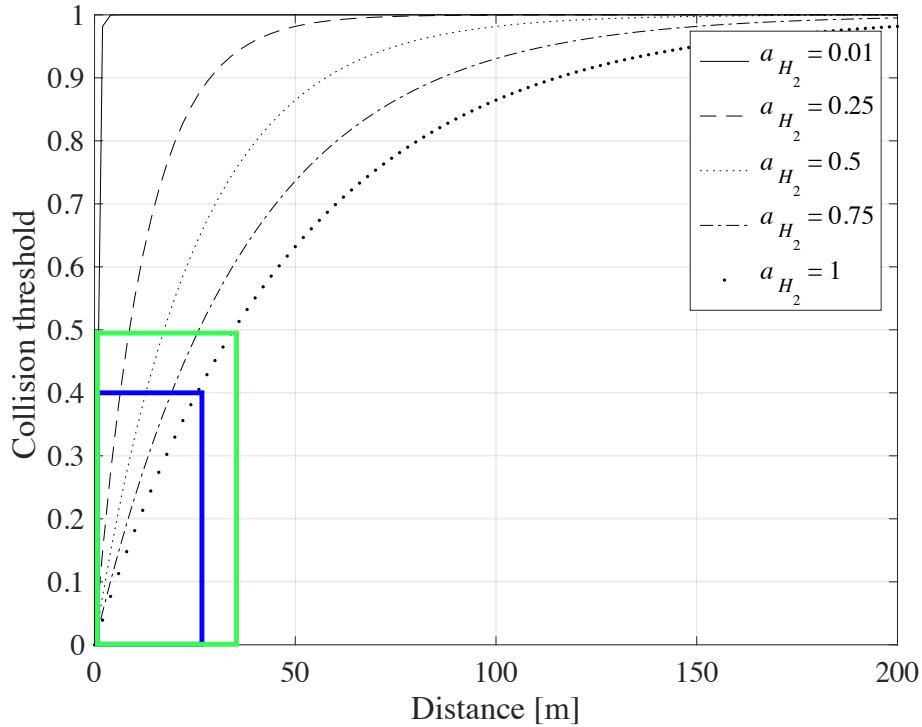


Fig. 6. Collision threshold versus the inter-vehicle distance (*i.e.*,  $d \leq z$  and  $z = 200$  m) under the hypothesis  $H_1$ , for different values of degree of activity in  $H_2$ .

$a_{H_2} = 1$  at a distance of 25 m from the source vehicle. At the same distance for  $a_{H_2} = 0.75$  it corresponds a collision threshold of 0.5 (see the *green rectangle*). Again, the behavior of the collision probability can be observed in Figure 7 varying the inter-vehicle distance specifically for (a)  $d = 50$  m, (b)  $d = 150$  m, and (c)  $d = 190$  m for  $d < 200$  m. For increasing distances the collision probability is higher, as well as for higher number of interfering vehicles the collision probability is higher. Finally, we observe that collisions can be affected also by the social parameter *i.e.*, the degree of activity in  $H_1$  and  $H_2$ . Indeed, as showed in Figure 3 a lower degree of activity in  $H_1$  corresponds to a lower forwarding probability, and then a lower collision probability.

### 3 SIMULATION RESULTS

In this section, we show the simulation results expressed in terms of throughput experienced at the next-hop forwarder vehicle. We assess the effectiveness of the SCARF technique with respect to a simple message dissemination protocol without social constraints. In this regard, we consider a scenario comprised of both socially-trusted (*i.e.*,  $S_{i,H_1} > 0.3$  with  $i = 1, \dots, N$ ) and asocial (*i.e.*,  $S_{l,H_1} \leq 0.3$ , with  $l = 1, \dots, N$ ) vehicles. All the vehicles are interested in the relevant content of a given VSN, namely  $VSN_1$ . This corresponds to the hypothesis  $H_1$ . Initially, we assume a packet arrival rate of 20, 50, and 100 packet/s, and a packet size of 1000 bytes.

The throughput has been computed for both the  $i$ -th socially-trusted and the  $l$ -th asocial next-hop vehicle laying at a distance of 150 m from the source vehicle (respectively, the *black* and *blue* lines in Figure 8). From Figure 8 we notice

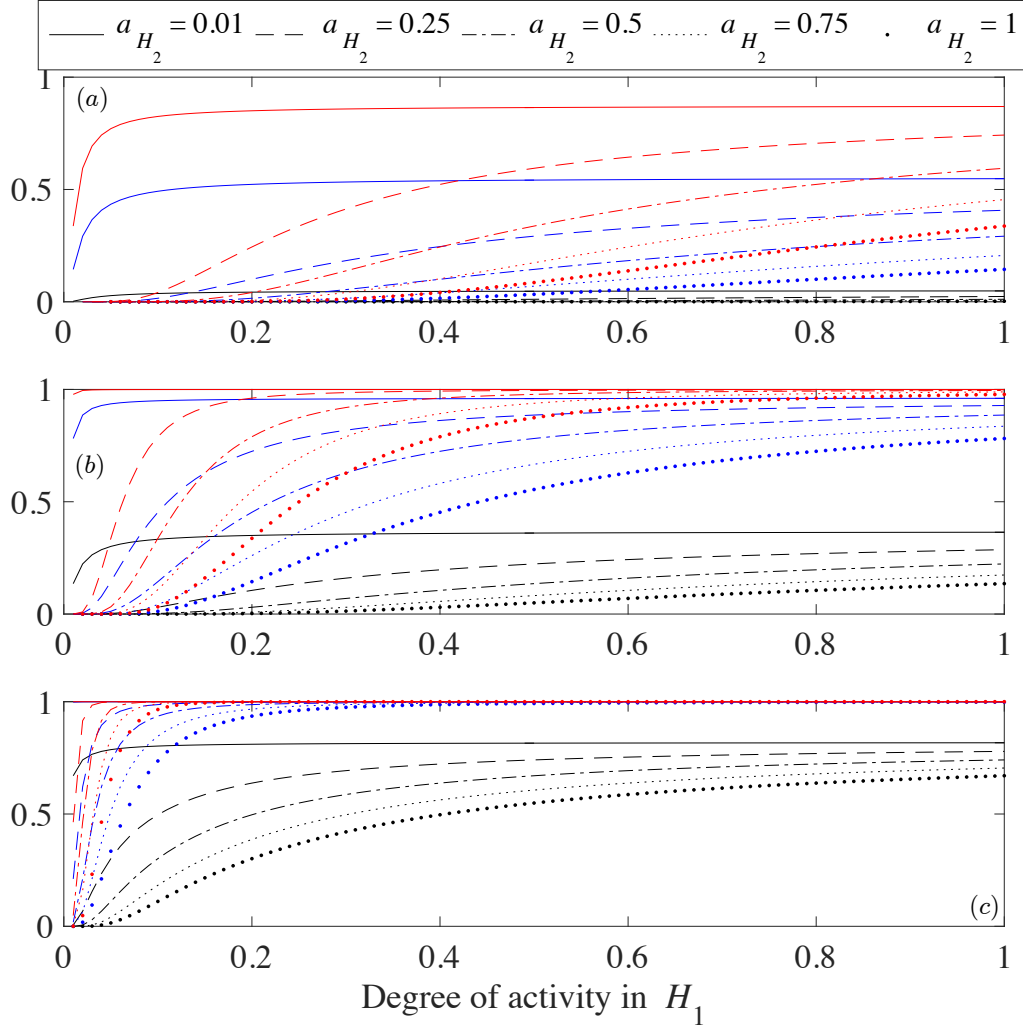


Fig. 7. Collision probability under the hypothesis  $H_1$  versus the degree of activity in  $H_1$ , for different values of interfering vehicles with this transmission range (i.e.,  $n = [2, 5, 10]$  for black, blue, and red curves, respectively) and the degree of activity in  $H_2$ , in case of (a)  $d = 50$  m, (b)  $d = 100$  m, and (c)  $d = 190$  m.

that, as expected, increasing the packet arrival rate corresponds to a higher throughput for the  $i$ -th socially-trusted vehicle, which reaches the maximum value for the highest degree of activity (i.e.,  $a_{H_1} = 1$ ). On the other hand, for the  $l$ -th asocial vehicle the throughput trend is independent from the degree of activity. Indeed, since the vehicle is asocial trusted, an increase of the degree of activity does not affect the probability of social-based forwarding as the SCARF technique selects only those vehicles with a social parameter higher than a given threshold (in our case,  $> 0.3$ ).

Figure 9 depicts the throughput trend depending on (i) the packet arrival rate [pkt/s] (i.e.,  $[1, 100]$ ), (ii) the degree of activity in hypothesis  $H_1$  (i.e.,  $0 \leq a_{H_1} \leq 1$ ), and (iii) the inter-vehicle distance (i.e.,  $d = [50, 100, 150]$  m), in case of (a)

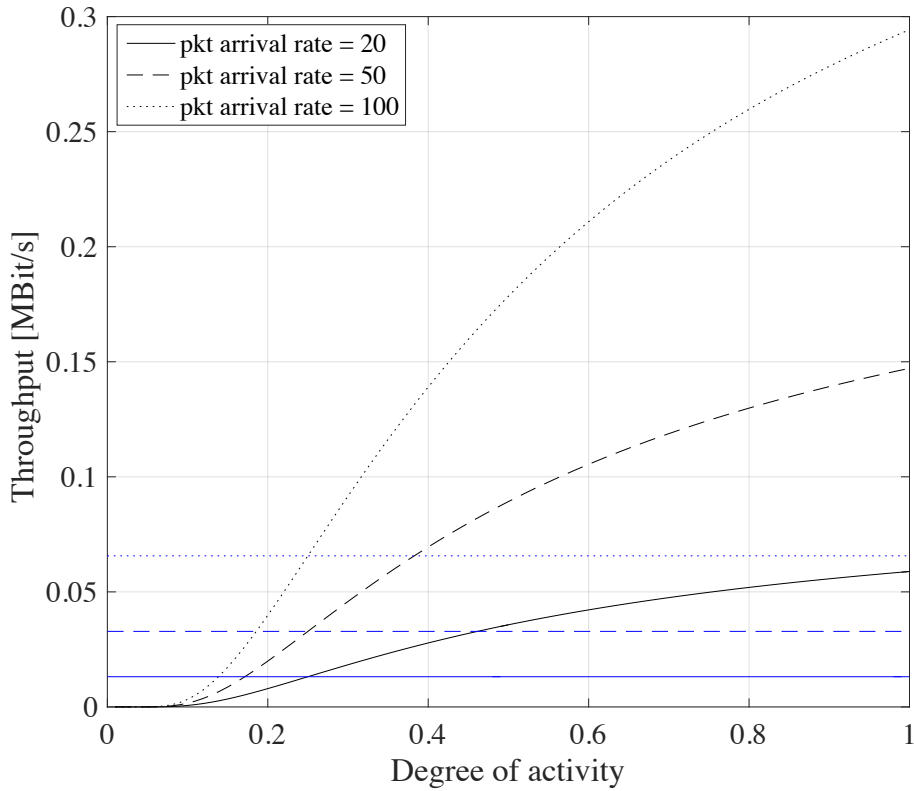
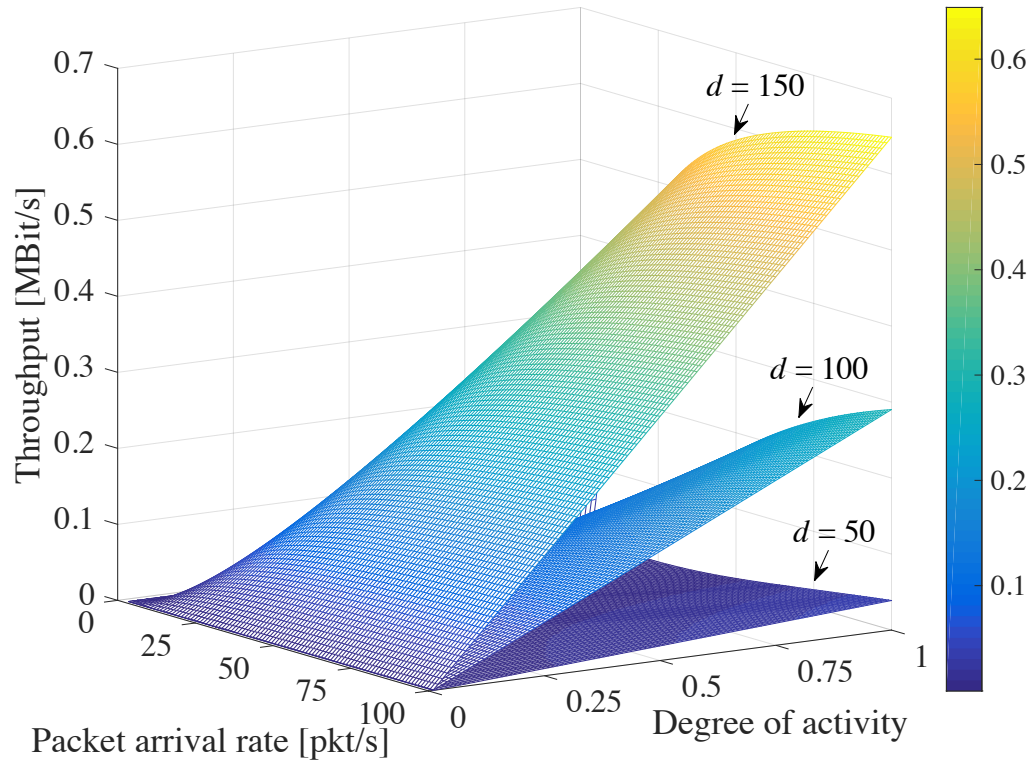


Fig. 8. Comparison of throughput [MBit/s] for a socially-trusted vehicle (*black lines*) and an asocial vehicle (*blue lines*), versus the degree of activity in  $H_1$  and different values of packet arrival rate, for a fixed distance of  $d = 150$  m.

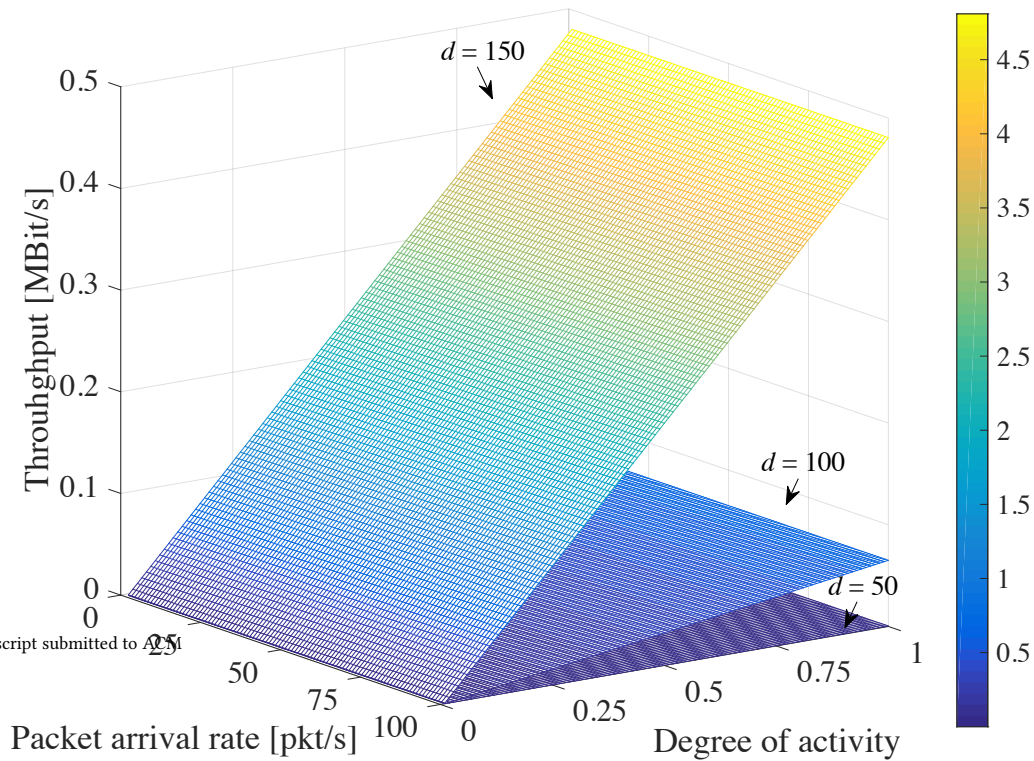
socially-trusted, and (b) asocial next-hop vehicle. We notice that the highest values of throughput are experienced for a socially trusted vehicle (see Figure 8 (a)). In both cases, we observe that highest trend is experienced for the longest inter-vehicle distance (*i.e.*,  $d = 150$ ) and the maximum value is obtained for the highest degree of activity and packet arrival rate. This corresponds to the higher forwarding probability for a vehicle that lays longer from the source and has higher degree of activity.

#### 4 CONCLUSIONS

In this paper we presented SCARF, a technique for message forwarding in VSNs. SCARF is based on the concept that not all the vehicles have the same social degree in a VSN, so that a few vehicles are considered as “socially-trusted”, while others as “asocial”. SCARF selects the most socially-trusted vehicle as next-hop forwarder, in order to guarantee reliable communications, while also guaranteeing a collision-aware mechanism.



(a)



(b)

Fig. 9. Throughput [MBit/s] versus the degree of activity in  $H_1$  and the packet arrival rate [pkt/s], for different values of inter-vehicle distance, in case of (a) socially-trusted, and (b) social next-hop vehicle.