Ad Hoc Networks 36 (2016) 409–424

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Position based routing in crowd sensing vehicular networks☆

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ARTICLE INFO

Article history:
Received 19 November 2014
Revised 5 June 2015
Accepted 8 June 2015
Available online 18 June 2015

Keywords:
Crowd sensing vehicular network
Position based routing
VANET
IEEE 802.11p

ABSTRACT

Using vehicles as sensors allows to collect high amount of information on large areas without the need to deploy extensive infrastructures. Although cellular technologies are presently the only solution to upload data from vehicles to control centers, in the next future short range wireless technologies could be used to offload part of this data traffic through vehicle to vehicle and vehicle to roadside communications. In such scenario, the greedy forwarding (GF) position based routing is an interesting algorithm to efficiently route packets from vehicles to the destination. However, GF suffers from the well known problem of local minima, which causes part of the packets to remain blocked in certain areas of the scenario. To deal with this issue, we propose two novel routing algorithms, specifically designed for crowd sensing vehicular networks (CSVNs): GF with available relays (GFAVR), fully distributed and independent of the scenario, and GF with virtual roadside units (GFVIR), exploiting a preliminary design phase where local minima are located. Through extensive simulations performed in different realistic urban scenarios, results demonstrate that both algorithms allow to improve data delivery by 10–40%, with negligible overhead and limited increase of complexity.

1. Introduction

Short range vehicular communications will enable in the next years the paradigm of connected vehicles. In August 2014, the National Highway Traffic Safety Administration (NHTSA), one of the main USA agencies in the field of transportation, issues an Advance Notice to proceed with standardization of vehicle to vehicle communication for light vehicles [2] and similar decisions will probably be taken by institutions of other Countries. It is thus expected that new vehicles will be soon equipped with wireless short range communication systems such as the wireless access in vehicular environment WAVE/IEEE 802.11p technology [3].

Even if this technology is primarily foreseen for safety purposes, other applications could take benefit from its deployment and the consequent creation of vehicular ad hoc networks (VANETs). In particular, short range multi-hop communications could be used to offload cellular networks, that are challenging an increasing bandwidth request; crowd sensing vehicular network (CSVN) applications are among the main specific applications where cellular offloading could be performed effectively [4]. Crowd sensing is an emerging paradigm that takes advantage of pervasive mobile devices (such as smartphones or in vehicle sensors) to efficiently collect data, enabling numerous large scale applications [5,6]. Focusing on vehicular scenarios, some million vehicles are today equipped with on board unit (OBUs) that periodically collect information from various sensors to be sent to a remote control center. Presently, they are used for insurance purposes and traffic estimations, but other applications have been proposed, like urban environment surveillance [7] or widespread pollution measurements [8]. For the moment, only cellular networks are used to upload data from the OBUs, with high costs in terms of billing and a large impact on cellular resource usage [9]. However, in the near future, short range road side units (RSUs) are expected to be

☆ This work was supported in part by the CNR project ICT for smart mobility (ICT4SM). Parts of this work were presented in [1].

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http://dx.doi.org/10.1016/j.adhoc.2015.06.005
1570-8705/

deployed in cities and highways to help collecting data from the vehicles.

Dealing with the use of short range technologies in CSVNs, the main issues to maximize the performed offloading are surely the RSU placement and the design of routing protocols [10–13]. As clarified in the further, even if several routing algorithms have been proposed for VANETs, in most cases they do not deal with the peculiarities of CSVNs or they are too complex for a large scale implementation. One protocol which represents a simple yet effective solution for CSVN is greedy forwarding (GF), which foresees that each OBU selects as next hop the neighboring OBU which maximally reduces the distance from the nearest RSU [14]. This protocol, however, suffers from the well known problem of local minima (or local optima), that causes packets to be collected in specific areas of the road network and never delivered to the RSUs [15,16]. This effect, the implications of which are further described in the paper, can be reduced by optimally placing RSU, as suggested for example in [10,11]. However, first this approach faces the constrains on site availability, which is not always guaranteed, and second it cannot eliminate the problem in all scenarios.

To deal with the local minima problem, even in the presence of non-optimal RSU placement, we propose two novel routing algorithms that are specifically designed for CSVNs. The first algorithm, denoted GF with available relays (GFAVR), is fully distributed, and foresees that each vehicle estimates its own positioning in a local minimum. The second algorithm, denoted GF with virtual RSUs (GFVIR), exploits a preliminary design phase where local minima are estimated and alternative routes are identified.

The effectiveness of both algorithms is shown through extensive simulations performed in two urban scenarios, characterized by different sizes and different vehicle densities: the city of Bologna (Italy) and the city of Cologne (Germany).

The paper is organized as follows: the related work is discussed in Section 2. In Section 3, the system model and the addressed problem are defined. Section 4 focuses on GF and the problem of local minima. The two proposed algorithms, GFAVR and GFVIR, are then detailed in Sections 5 and 6, respectively. The assumptions made and the simulation settings are shown in Section 7 and results are provided in Section 8. Finally, our conclusion is given in Section 9.

2. Crowd sensing vehicular networks and related work

Due to the wide diffusion of consumer devices with sensing abilities, such as smartphones and media players, their use to obtain large scale information from the environment (crowd sensing) has recently drawn considerable interest from researchers and industries [5,6].

This paradigm has been also investigated in the vehicular scenario adopting several other names, including vehicular sensor networks (VSNs) (e.g., in [17]), probe vehicles (e.g., in [18]), or floating car data (FCD) (e.g., in [19]). An interesting survey on this topic can be found in [20]. Among the example applications that have been envisioned we can cite the improvement of urban environment surveillance [7], the provision of large scale pollution measurements [8], the alerting of upcoming vehicles when an accident is observed [21], and the enabling of traffic monitoring [22]. Besides possible applications, many other aspects have been investigated, like the data management at the control center [23] and the aggregation of messages among neighbor vehicles to reduce the amount of information sent to the control center [24].

CSVNs can be seen as the intersection of wireless sensor networks (WSNs) and VANETs; their peculiarities are [25]:

- nodes collect information to be delivered to a control center (like in WSNs);
- the high mobility makes the node density and the network topology changing frequently (like in VANETs).

To collect the information from OBUs, CSVNs can rely on either cellular networks or short range communications. In the latter case, the overall architecture must be completed with the placement of RSUs, connected to the control center, and one of the main challenging aspects is the definition of the routing protocol that allows data to reach these RSUs. Several routing protocols have been proposed for VANETs in the last years, including those described in [12,13,26]. Some of the proposed algorithms, including as an example CAR [27], are reactive, i.e., they search for a path towards a destination only when a packet to that destination is enqueued. This approach is normally preferable in slowly variable ad hoc networks, since it minimizes the signaling overhead; however, the main drawbacks are that i) it needs a search phase to define the route, which might be a problem in the quickly variable vehicular scenario, and ii) it suffers from scalability problems in large networks [28]. For these reasons, and based on the possibility to send periodic messages for safety purposes (denoted as beaconing in the further), most protocols are proactive, i.e., they continuously update a table towards the possible destinations, independently from the presence of packets to that destination in the transmission queue. Examples are greedy perimeter stateless routing (GPSR) [15] and Greedy Perimeter Coordinator Routing (GPCR) [16]. Some protocols, such as EPIDEMIC [29] or SPRAY&WAIT [30], also foresee the use of multiple copies. Allowing multiple copies of a packet, however, has the drawback that no OBU carrying one of the copies knows whether the other copies have been already delivered or not, increasing, in general, the network load. Finally, several algorithms rely on additional and detailed (thus costly) information that must be carried by OBUs, such as road maps (e.g., GeoSVR [31]), traffic signal schedule (e.g., ROAMER [32]), information on buses and their routes (e.g., SKVR [33]), or the routes that are daily traveled by vehicles (e.g., PER [34]).

Although most protocols designed for vehicular networks can be also applied to CVSNs, only a few proposals have been explicitly designed for a CVSN scenario, characterized by the fact that the position of the destination (one of the RSUs) is fixed and known by vehicles [25]. To this regard, an algorithm that perfectly suites to this scenario is the GF, which also has other useful properties, as detailed in Section 3. Unfortunately, the presence of local minima tends to decrease the performance of such algorithm [15,16], as deepened in Section 4. To overcome this important limitation, we propose and investigate the performance of the two novel routing protocols that are explicitly designed for CVSN scenarios.