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Query-response geocast for vehicular crowd sensing

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ABSTRACT

Modern vehicles are essentially mobile sensor platforms collecting a vast amount of information, which can be shared in vehicular ad hoc networks. A prime example of a resulting vehicular crowd sensing application might be the search for a parking spot in a specific geographic area. The interested vehicle sends a corresponding query into the destination area—a technique known as geocast. As the query originator, however, is likely to have moved relatively far away from the location from where the query was started by the time the response arrives, an efficient routing approach towards the originator is required. In this paper, we extend the Breadcrumb Geocast Routing (BGR), a georouting protocol for vehicular networks that is able to close this functional gap. We introduce several performance improvements. In particular, we focus on further reducing both the delivery delay and network overhead and on the dynamic adaption of breadcrumbs to the street layout, node density and other scenario-specific parameters. Extensive simulations in four different urban scenarios show a significant improvement on BGR, especially in terms of delivery delay, which can be reduced by an average of 24%. Breadcrumb Geocast Routing Version 2 (BGR2) thus not only avoids up to 93% of the traffic overhead of Epidemic, but increases the delivery rate of the underlying georouting protocol significantly from about 48% to almost 100% even in difficult scenarios. In sum, it is shown that BGR2 and breadcrumbs in general are a feasible and efficient approach for the routing of query responses to moving nodes via geocast, enabling a variety of vehicular crowd sensing applications.

1. Introduction

It is envisioned that there will be more than one billion connected vehicles roaming the streets by 2020 [1]. With the proliferation of automotive ad hoc communication[1] and sophisticated sensor systems, a vast amount of information becomes available to enable a plurality of new cooperative services in Intelligent Transportation System (ITSs), including traffic management, electronic toll collection, safety, and infotainment. While many applications already make use of locally available sensors, e.g., radar for distance warning, only few actual applications use sensor information from remote systems. Primarily, vehicular networking research has been focused on developing vehicular safety communication systems. Naturally, the automotive industry and governments worldwide see safety applications (based on a proactive communication model), such as collision avoidance, as an effective means to reduce traffic accidents, fatalities, and, in case of the industry, through advanced driver assistance systems to set themselves apart from competitors [2]. Beyond the initial focus on vehicular safety applications, though, a reactive (i.e., query–response) model indeed allows “exploiting the wisdom of the crowd” [2] by requesting specific information from any number of vehicles even over larger distances. This information may not need to be subject to large-scale dissemination as it might either be of specific interest only or consume both too much bandwidth and processing power in

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[1] http://www.car-to-car.org/

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the network, e.g., sharing image data for up-to-date street-view impressions. As these data are not time-critical and since there is often no end-to-end path between two vehicles willing to share data in the first place (due to the highly dynamic structure of vehicular networks, for instance), a Delay-/Disruption-Tolerant Network (DTN) following a store-carry-forward approach is required. A prime example of a resulting vehicular crowd sensing application might be the search for a parking spot in a specific geographic area. The interested vehicle sends a corresponding query into the (stationary) destination area—a technique known as geocast. As the query originator, however, is likely to have moved relatively far away from the location from where the query was started by the time the response arrives, an efficient routing approach towards the originator is required. Typical approaches are to flood the network or to guess a destination area large enough that it might still include the originator, both of which do not scale well.

1.1. Contributions of this paper

This paper builds on previously published work [3]. The prior work presented a novel approach for routing responses to a moving query originator—the BGR protocol. Originators leave a trail of floating content [4] areas, which we refer to as *breadcrumbs* and which can be used to efficiently forward the response to its destination. As BGR can be used on top of different (existing) georouting mechanisms, it adds an efficient means to address moving originators even to protocols formerly ignoring the problem.

In this paper, we significantly extend our previous work summarized in Section 3 by (a) a detailed analysis of room for improvement and deriving multiple new protocol features in Section 4, (b) an expansion of the simulation environment, including twice as many scenarios covering a variety of urban theaters of operation and adopting default settings to better match related work on IEEE 802.11p, as well as (c) an extensive evaluation of the proposed protocol features, both separately and in combination, in Section 5. Finally, we combine the results to derive a proposed update to the protocol as BGR2, which we investigate in comparison with the original BGR as well as several reference protocols, showing major improvements in terms of delivery delay, message overhead, and applicability to various street layouts. Naturally, we extend the investigation of prior work in Section 2 to include the latest state-of-the-art with regard to both vehicular georouting and the new protocol features proposed in this work.

1.2. Outline

The remainder of this paper is structured as follows. We begin in Section 2 by studying what other authors have achieved in this field and how it relates to our work. We define relevant concepts and summarize the BGR protocol in Section 3. We propose protocol extensions to improve the performance in Section 4. We describe the extended simulation setup and extensive evaluation results of the proposed features in Section 5. Finally, the paper concludes in Section 6.

2. Related work

A plethora of routing protocols exists in the literature. In this paper, we therefore only consider research work focusing on the problem of georouting in the vehicular domain and, in particular, on the problem of routing messages to moving nodes.

2.1. Georouting

A recent survey [5] of geocast routing protocols for Vehicular Ad Hoc Networks (VANETs) presents geocast protocols addressing the difficulties of this domain, such as “high mobility, frequent changes in topology, high and frequently variable density, long lifetime of nodes and regular moving patterns” [5]. However, none of the approaches solves the problem of sending replies to moving nodes, since they all require a static destination area [6–8]. Further, the source node has to be part of this area [9], which then becomes unnecessarily large if messages must overcome larger distances. BGR can be used on top of arbitrary geocast protocols, adding this missing capability.

Geocast routing protocols in VANETs can further be categorized according to their primary target traffic environment, namely urban and highway. [10] Since BGR’s purpose is to support crowd sensing applications in urban environments, we thus focus on the former group. T-TSG [11] warns vehicles after an accident. It selects forwarding vehicles based on the traffic light situation. Although the dissemination of a warning message in a geographic region is similar to keeping breadcrumb messages alive in their anchor zone, T-TSG focuses on this step and only supports relatively small distances. Coverage-aware Geocast Routing (CAGR) [12] measures vehicles’ coverage capability to only forward messages to those with high delivery probabilities. Obviously, this requires all vehicles to have knowledge about their own trajectory as well as to collect and maintain trajectories of all encountered vehicles in order to compute a coverage graph. Although BGR can use trajectory information, it does not depend on it, as opposed to other works [13–15]. In [15], the authors use the route information from car navigation systems or, if available, the predefined routes (e.g., bus and tram routes) to route messages from vehicles to Roadside Units (RSUs). Vehicles exchange their intended route periodically. Further, the authors address the communication between a vehicle and an RSU, so destinations are fixed and known a priori. Vehicle Density and Load Aware (VLDA) [16] constructs a route based on real-time vehicle density, traffic load, and distance to the destination. Thus, messages are avoided being sent to areas with sparse connectivity and network load is balanced. Similarly, BGR makes use of real-time vehicle density to determine suitable routing parameters. Again, none of the abovementioned protocols takes routing of query responses to a mobile destination into account.

Geographic Source Routing (GSR) [17] also proposes a routing strategy for VANETs in city environments. Yet, in order to find a vehicle’s position, it floods the network with a position request. Further, it requires digital map data for optimization purposes. BGR, in contrast, does neither flood the network, nor does it require digital maps.