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Road-side units operators in competition: A game-theoretical approach

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ABSTRACT

We study the interactions among Internet providers in vehicular networks which offer access to commuters via road side units (RSUs). Namely, we propose a game-theoretical framework to model the competition on prices between vehicular Internet providers to capture the largest amount of users, thus selfishly maximizing the revenues. The equilibria of the aforementioned game are characterized under different mobile traffic conditions, RSU capabilities and users requirements and expectations. In particular, we also consider in the analysis the case where mobile users modify the price they accept to pay for the access as the likeliness of finding an access solution decreases.

Our game-theoretical analysis gives insights on the outcomes of the competition between vehicular Internet providers, further highlighting some counter-intuitive behaviors; as an example, comparing with the case when users have constant price valuation over time, having users inclined to increasing their "acceptable" price may force vehicle Internet providers to charge lower prices due to competition.

1. Introduction

Vehicular Ad-hoc NETworks (VANETs) recently attracted much interest from the research community as a core networking component to build up intelligent transportation systems (ITS) to improve road safety, optimize the humans and goods mobility, and disseminate real-time context information on traffic loads, congestion and hazardous situations. The applications enabled by VANETs are not only limited to safety-oriented ones, but also extend to *leisure* applications related to Internet access and entertainment along the road. A comprehensive classification of VANETs applications can be found in [12].

The design of VANET architectures to support *leisure* applications has attracted the attention of recent work and researchers; as an example, the Drive-thru Internet [22] project targets the provision of affordable Internet connections to vehicular users through road side Wireless LAN infrastructure. The scope of the research covers network access, roaming, handover, authentication, etc., and the achieved results show that despite a number of technical challenges to be addressed, providing Internet for highly mobile vehicular users is possible [21–23,25]. The CABERNET [7] and Infostations [28] projects propose architectures similar to Drive-Thru Internet. Motivated by these works, we expect that the provision of Internet connectivity via road side infrastructure will be a flourishing market in the next future attracting Internet providers which may possibly compete among themselves. This competition may have a valuable impact on customers welfare, as well as influence the quality and cost of all aforementioned features about road safety.

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The scientific literature already counts a number of studies of competition between *classical* Internet access providers (see, e.g., [1,15] or [16, Chapter 5]). In many cases, the interactions among users (through congestion) are also considered, and taken into account by access providers [9,10]. However, to the best of our knowledge the case of provider competition in vehicular networks has not been deeply investigated, although it has some important specificities; indeed customers are mobile and move in a limited speed range and, more importantly, in constrained directions. In this work we want to fill this gap by providing a study of duopoly competition, between providers owning one road side unit (RSU) each, along a stretch of road. These road side units are able (besides all other features) to provide Internet access to mobile users, whose cars are equipped with a device called on-board unit (OBU). We study how providers strategically set their price for providing Internet connectivity in response to the competitor's pricing strategy with the selfish objective of revenue maximization; vehicular users may decide to get Internet connectivity from one operator or the other depending on the corresponding price and the current network conditions. This manuscript builds on our preliminary work in [11], further extending the network scenario by considering that users can change their acceptance/refusal strategy (or equivalently, their price preferences) while they travel along the stretch of road. We investigate how this variation influences the pricing strategies of providers. Such a question is linked to the specificities of vehicular networks, and to the best of our knowledge has not been studied in the scientific literature. Among the unexpected results, we observed that users increasing their price acceptance threshold between the two RSUs, if anticipated by providers, strongly impacts the competition among them and can lead to lower prices and lower provider revenues (with respect to the case when users have fixed price acceptance thresholds).

The manuscript is organized as follows: Section 2 gives an overview of the related work further commenting on the main novelties and contributions of the present work; Section 3 introduces the reference scenario and the related modeling assumptions; in Section 4, we analyze the case where the pricing policy of one vehicular Internet provider is fixed and the competitor best-responds to it. Section 5 analyzes the non-cooperative game between vehicular Internet providers, focusing on the consequences in terms of provider revenues and user welfare. Further comments on the modeling assumptions and concluding remarks are reported in Section 6.

2. Related work

Though vehicular networks are far from being widely deployed, the research community already started to extensively study different problems and challenges likely to arise in the future. Many articles are devoted to the definition/adaptation of communication protocols for the vehicular context (like in [3,14,33–35]), studying the suitability of already existing technologies and proposing new approaches. The main challenge here is to develop a reliable protocol for V2V communications.

The suitability of WLAN hotspots for providing Internet access in vehicular scenario is studied in [7,22,28]. In [22], mobile users exploit temporary WLAN connections during their road trip to download/upload contents form/to the Internet; the main challenge addressed in this work is to maintain a seamless connectivity even if the physical connection with a road side access point may get lost temporarily. Along the same lines, automatic access point association/deassociation procedures are studied in [24,26] in the very same vehicular network architecture. Besides a purely theoretical studies, special equipments for highly mobile scenarios are in development, among which a router with 3G and WLAN interfaces is designed to ensure seamless handovers, proposed by NEC Corporation in 2005. In [25], the authors discuss the requirements for such a router and test their own prototype of modular access gateway.

Another research area related to this work deals with the optimal design of vehicular networks, where the problem mainly scales down to efficiently deploying RSU to maximize the "quality" perceived by the mobile user in terms of download/upload throughput, and/or latency to retrieve contents form the Internet through the deployed RSUs. Trullols et al. [30] consider different formulations for the deployment problem and introduce heuristics based on local-search and greedy approaches to get suboptimal solutions. A solution based on genetic algorithms is studied by Cavalcante et al. [4]. Yan et al. [32] study the optimal RSU deployment problem, where candidate places for RSU location are crossroads. A comprehensive description of the general problem of optimal RSU deployment by a single entity can be found in [2] and [36]. A different scenario, where several providers deploy their RSUs in a competitive manner is studied in [8], and the same problem but for general wireless networks is considered in [1].

Researchers often use game theory to study competition between providers. In [19] the authors survey various game-theoretic models for evaluating the competition between agents in vehicular networks. The mobile users competition is studied in [20], where users share the same RSU. In [18] a hierarchical game is proposed to analyze the competition between OBUs and RSUs. Differently, in [27] a coalition formation game among RSU is analyzed, with the aim of better exploiting V2V communications for data dissemination. More generally, good surveys on game theory applications in wireless networks are [5] and [29].

In this paper, unlike in the previously described references we ignore V2V communications and focus only on users which aim to establish Internet connection. In that context, we consider price competition between Internet access providers in the case of vehicular networks, which is, to the best of our knowledge, a novel issue. The scientific literature contains several analyses of provider competition in general wireless networks (e.g., [6,17,31]), but, even if V2I networks bear some similarities with generic wireless access networks, they have specific features which make the pricing problem worth analyzing. Indeed, in generic wireless access networks, the network operator competition is generally over the "common" users, that is, those users which fall in the coverage area of the competing network providers. In other words, competition between providers arise only if the coverage areas of the networks (partially) overlap as in [17]. Users