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Deployment of roadside units based on partial mobility information

Cristiano M. Silva [a,b,*], Andre L.L. Aquino [c], Wagner Meira Jr. [b]

[a] Departamento de Tecnologia – Universidade Federal de São João Del-rei (DTECH/UFSJ), Rod.: MG 443, KM 7, Ouro Branco, MG CEP 36420-000, Brazil
[b] Departamento de Ciência da Computação – Universidade Federal de Minas Gerais (DCC/UFMG), Av. Antônio Carlos 6627 (ICEx), Belo Horizonte, MG CEP 31270-010, Brazil
[c] Instituto de Computação – Universidade Federal de Alagoas (IC/UFAL), Av. Lourival Melo Mota, s/n, Cidade Universitária, Maceió, AL CEP 57072-900, Brazil

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ABSTRACT

This work presents an algorithm for deployment of roadside units based on partial mobility information. We propose the partition of the road network into same size urban cells, and we use the migration ratios between adjacent urban cells in order to infer the better locations for the deployment of the roadside units. Our goal is to identify those α locations maximizing the number of distinct vehicles experiencing at least one V2I contact opportunity. We compare our strategy to two deployment algorithms: MCP-g relies on full mobility information (full knowledge of the vehicles trajectories), while MCP-kp does not assume any mobility information at all. Results demonstrate that our strategy increases the number of distinct vehicles contacting the infrastructure in 6.8% when compared to MCP-kp. On the other hand, MCP-g overcomes our strategy by 8.5%. We must evaluate whether the 8.5% improvement worthies tracking the trajectories of vehicles. Complementary, the marginal contribution of adding a new roadside unit becomes much more assertive when employing our strategy, enabling a better evaluation of the return on investments by network designers. Such guarantees are not provided by MCP-kp, and they are too weak in MCP-g.

1. Introduction

Vehicular networks [1] are expected to hit the streets soon. The European Union indicates that communication technologies combined with automation are the keys for improving the safety, efficiency and environmental friendliness in transportations [2]. Vehicular communication may be rather favored through the provision of access points along the roads (roadside units). When designing the roadside infrastructure for vehicular networks we intend to prioritize a subset of locations to receive the roadside units in order to allow an incremental development of the infrastructure.

In this work we report a novel strategy to allocate the roadside infrastructure for vehicular networks using the global behavior of drivers. Instead of assuming full knowledge of vehicles trajectories, we assume knowledge about migration ratios between adjacent urban locations. We name it "partial mobility information". We model the allocation of the roadside units as a Probabilistic Maximum Coverage Problem (PMCP), a weighted approach for the traditional Maximum Coverage Problem [3]. We consider the location of each vehicle no longer deterministic, but model it as a probabilistic distribution function given by $p:\{c_1,c_2,P\}\longrightarrow\mathbb{R}$ that returns the likelihood that a vehicle located at urban cell c_1 migrates to urban cell c_2 considering the migration ratios provided by mobility model P.

This paper is divided into two complementary parts: in the first part we present our method considering a synthetic 9×9 grid road network. In this setup we consider that roadside units are always located at roads intersections, and our goal is to demonstrate our deployment strategy in a step-by-step basis. In this scenario, our partial mobility information consists of turning ratios at roads intersections.

In the second part of the paper we evaluate our deployment algorithm considering realistic conditions (real road network and realistic flow). Our first challenge is to represent road networks of arbitrary topology. We propose partitioning the road network into a grid-based structure composed of urban cells. An urban cell may hold several blocks, thus our initial approach based on turning ratios at roads intersections is replaced by a model that considers the migration ratios between adjacent urban cells. Among a variety number of optimization targets, we choose to maximize the

* Corresponding author at: Departamento de Tecnologia – Universidade Federal de São João Del-rei (DTECH/UFSJ), Rod.: MG 443, KM 7, Ouro Branco, MG CEP 36420-000, Brazil.

E-mail addresses: cristiano@ufsj.edu.br (C.M. Silva), alla@ic.ufal.br (A.L.L. Aquino), meira@dcc.ufmg.br (W. Meira Jr.).

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number of distinct vehicles contacting the infrastructure, an interesting metric when we intend to collect and disseminate small and self-contained traffic announcements [4].

We propose PMCP-b, a deployment algorithm based on partial mobility information. We compare our deployment algorithm to MCP-g and MCP-kp, both heuristics proposed by Trullols et al. in [4]. MCP-g is the greedy solution for the Maximum Coverage Problem [3], and it relies on the trajectories information of each vehicle. We say that MCP-g relies on full mobility information. On the other hand, MCP-kp does not assume any mobility information at all.

Our results demonstrate that:

- By covering[1] 2.5% of Cologne[2] (selection of 250 urban cells in a set of 10 000), we achieve the following coverage of distinct vehicles: MCP-g = 98.1%; PMCP-b = 89.6%; MCP-kp = 82.8%. PMCP-b improves MCP-kp in 6.8%, while MCP-g improves PMCP-b in 8.5%. We evaluate whether the 8.5% improvement worthies tracking the trajectories of individual vehicles;
- The number of V2I contact opportunities per roadside unit in PMCP-b presents a clear lower bound offering minimum guarantees of efficiency for network designers. Such guarantees are not provided by MCP-kp, and they are too weak in MCP-g;
- A typical vehicle driving in MCP-g experiences at most 25 infrastructure contacts. In PMCP-b, a vehicle experiences up to 60 contacts. In MCP-kp it may reach up to 75 contacts during a single trip. PMCP-b and MCP-kp presents more V2I contact opportunities because they concentrate the roadside units at popular locations. The strategy to concentrate the roadside units in popular locations also has a side-effect: 17.03% of the MCP-kp vehicles never cross any roadside unit. For a matter of comparison, PMCP-b measure is 10.12%, while MCP-g measure is just 1.86%.

The main contribution of this work is the proposal of a deployment algorithm based on a novel paradigm of mobility information, i.e., partial mobility information. Initial deployment works typically propose the allocation of roadside units at the most crowded locations of the road network, and they do not assume any mobility information at all (assumption inherited from the cellular networks).

On the other hand, modern deployment works propose strategies assuming full knowledge of vehicles trajectories (full mobility information). However, full knowledge of vehicles trajectories is a hard assumption when we consider a real deployment because: (i) knowledge of vehicles trajectories implies in several privacy issues; (ii) processing the vehicles trajectories requires a large processing effort: thus, we may not be able to propose dynamic deployment strategies of mobile roadside units; (iii) the network designer may not have the trajectories information available.

Thus, in this work we propose a deployment strategy based on partial mobility information, and we compare our approach to a deployment strategy that allocates the roadside units at the most crowded locations (MCP-kp), and a deployment strategy considering full mobility information (MCP-g).

This work is organized as follows: Section 2 presents the related work. Section 3 discusses the Maximum Coverage Problem. Section 4 formalizes the Probabilistic Maximum Coverage Problem. Section 5 presents a didactic comparison of PMCP-b, MCP-g, and MCP-kp considering a 9×9 grid road network. Section 6 generalizes our algorithm to handle real road networks. Section 7 presents the experiments considering the realistic Cologne scenario. Section 8 concludes our work.

2. Related work

Researchers have been studying the allocation of roadside units in vehicular networks through several points of view: some works propose analytic models to address some specific aspect of the deployment. Nekoui et al. [6] propose the definition of an infrastructure for vehicular networks based on the conventional definition of the transport capacity. Complementary, Alpha Coverage [7] provides worst-case guarantees on the interconnection gap while using fewer roadside units. The contact probability is also considered: Zheng et al. [8] present the evaluation of a deployment strategy through the contact opportunity, and Lee and Kim [9] propose a greedy heuristic to place the roadside units aiming to improve vehicles connectivity while reducing disconnections.

Strategies for content download between roadside units and vehicles are also analyzed: Fiore et al. [10] introduce a mixed-integer quadratic programming based optimum roadside units deployment scheme to provide Internet access services for the maximum road traffic volumes with limited number of roadside units. Liu et al. [11] propose a new roadside units' deployment strategy for file downloading in VANETs.

Genetic programming is proposed by Lochert et al. [12] and Cavalcante et al. [13] to solve the deployment. Geometry-based heuristics are also exploited: Cheng et al. [14] propose a geometry-based coverage strategy to handle the deployment problem over urban scenarios. Patil and Gokhale [15] propose a Voronoi [16] diagram-based algorithm for the effective placement of roadside units using packet delay.

Some works propose heuristics for the deployment of roadside units: Lee and Kim [9] propose a greedy heuristic to place the roadside units aiming to improve vehicles connectivity while reducing disconnections. The heuristic counts the amount of reached vehicles at each intersection considering the transmission range of the roadside units. Yan et al. [17] propose a class of algorithms named Tailor. Jeonghee et al. [18] proposes the concept of "intersection connectivity".

The use of the existing network infrastructure at urban centers is also investigated: Liang and Zhuang [19] propose the use of the wireless LAN for data dissemination. Marfia et al. [20] propose the use of open access points. Tonguz and Viriyasitavat [21] propose the utilization of vehicles as roadside units by using a biologically inspired self-organizing network.

Partitioning road networks has already been proposed in the literature. However, the authors employ the partition of the road network as an intermediate step to accomplish: (i) simplified analytic modeling of the problem [22]; (ii) subdivision of the problem into several smaller ones [23]; or even (iii) simplified road network consisting of only horizontal and vertical roads [24,25].

Our work differs from all previous ones in the sense that we propose a deployment algorithm applying the partition of the road network, and assisted by partial mobility information.

3. Maximum Coverage Problem

Trullols et al. [4] model the deployment of roadside units as a Maximum Coverage Problem. In order to cover a given region, MCP-g iteratively selects those α intersections having the largest number of uncovered vehicles ("uncovered" means that a vehicle has not reached any roadside unit during the trip). Formally:

[1] We are assuming a slightly different concept of "coverage": traditional usage of coverage indicates a continuous region where users have high probability of connection. But, because we are assuming *infostations* [5], we consider small islands of coverage: fragmented and possibly disconnect areas where users are supposed to meet connection.

[2] Available traces in: http://kolntrace.project.citi-lab.fr/.