Transportation Research Part C 53 (2015) 35–47

Contents lists available at ScienceDirect

Transportation Research Part C

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

Locating fixed roadside units in a bus transport network for maximum communications probability

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ARTICLE INFO

Article history:
Received 25 June 2014
Received in revised form 30 January 2015
Accepted 30 January 2015
Available online 19 February 2015

Keywords:
Location
Probabilistic models
Coverage
Vehicular *ad-hoc* networks

ABSTRACT

A key issue in solving the difficult bus-bunching problem is being able to have reliable information about the location of the buses in the network. Most advanced public transport systems have buses with GPS devices, but the problem remains of how to send reliable information from the buses to the control unit, particularly when the density of buses is low, but there are high communications reliability requirements. As a solution, we study locating roadside units (RSUs) along the route. The buses, together with the RSUs, form a linear vehicular ad-hoc network (VANET). The RSUs are deployed so to maximize the probability of a vehicle communicating with an RSU in at most two hops. Previous studies on RSU location never took into account two hops, a conceptually different type of network. Rather, they consider that a vehicle is able to communicate only directly to an RSU (one hop), which is a well-known Maximum Covering Problem, in which *one of the parties is always immobile*, similar to a mobile phone network. Oppositely, our method solves the problem in which *two of the intervening parties are mobile and communicate with each other*, not possible to solve as a Maximum Covering Problem. We estimate the probability of a vehicle accessing successfully an RSU either directly or through the relay of another vehicle. This probability is later embedded in an integer programming formulation that optimizes the RSU locations for maximum communications likelihood.

Numerical examples show that the connection probability is strongly dependent on the coverage ratio of the transmitters and receivers and relatively independent on the vehicle density on the network, when densities are low. Results also show that it is possible to find some cost-efficient solutions which result in a smaller number of RSUs located while assuring a connection probability of 0.9 or higher.

1. Introduction

In a public transport system seeking to maintain an efficient service, the information about the real time locations of buses is very important. Each bus is typically equipped with a GPS module and requires sending information about its own position and, also, relaying information from other buses to the control center. When the bus density is low, fixed relay communication nodes need to be deployed at selected sites along the route, known as roadside units (RSUs). The resulting communications network is a *vehicular ad-hoc network* (VANET). In such a network, the vehicles can communicate among themselves and also with some fixed infrastructure deployed along the road. In the most general case, the architecture is

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http://dx.doi.org/10.1016/j.trc.2015.01.032
0968-090X/

composed by on board communications units (OBUs) which provide wireless communication, and RSUs. Therefore, two types of communications are possible: Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I). VANETs play an important role in the development of Intelligent Transportations Systems, with applications oriented to traffic control and road safety (Zeadally et al., 2010). In these applications, infrastructure nodes collect information from vehicles, to be used for network operation at the control center.

In a VANET, it is important to find the optimal locations for the RSUs in order to improve the likelihood of a timely communication. Optimal deployment of RSUs has been dealt with using different objectives and methods. Li et al. (2007) consider the problem of gateway placement for Internet access in vehicular networks, demanding full coverage by already located RSUs. Trullols et al. (2010) formulate a Maximum Covering optimization problem to find the optimal strategy for deploying a fixed number of RSUs, in order to maximize the number of vehicles that are within the coverage area of an RSU, i.e., using only one hop to communicate, and rely on perfect knowledge about the number and movement of vehicles throughout the network. Furthermore, they use a heuristic that does not guarantee an optimal solution. Aslam and Zou (2011) propose a scheme for locating a fixed number of RSUs so to minimize the time it takes to a vehicle to report an event, again, through just one hop, and they assume that the RSUs can be located at any point or place in the network. The information waits to be delivered until the vehicle is within reach of an RSU.

None of these papers considers a system in which there is information relaying through other vehicles, a proper VANET. In this case, going from a context in which communications are directly between vehicles and RSU's only, as in Li et al. (2007), Trullols et al. (2010) and Aslam and Zou (2011), to a situation in which two hops are allowed (Vehicle – RSU communication through a second vehicle, i.e., two hops) makes a significant difference, since it is a different type of network.

In our case, the network is a true VANET, or ad-hoc network, in which the vehicles are also communications relays, carrying in some cases the communications of other vehicles. This is a different concept: vehicles can communicate with each other, which makes the problem more complex, not possible to solve using a Maximum Covering Problem or any of the methods used in the references, since *these methods always assume communications between two parties, one of which is immobile* (the RSU), as opposed to three, in which two are mobile, as in our case. We assume that all vehicles are VANET-equipped (which is the case of the public transportation vehicles of the case study), which allows the communications system to work with a fewer number of RSU's, because the road does not need to be wholly covered by RSU's, and because other vehicles replace part of the RSU's required for a speedy communication. Both the concept and the probabilistic analysis of this situation are very different to those in Trullols et al. (2010) and Aslam and Zou (2011).

We propose an optimization model that maximizes the probability of the bus and the RSU to be connected, and determines the location of a predefined number p of RSUs. We assume that the potential RSU location point candidates are also predefined (by cost constraints and/or availability of sites). The optimization model is intended to work in a low vehicle density scenario with high communication reliability requirements. The model maximizes the probability of the vehicles establishing a direct (one-hop) or indirect (up to two-hops) communications link to an RSU. This probability depends on the vehicular density, the radio coverage of the units, the distance between adjacent RSUs, and the wireless channel model. In addition, we analyze the trade-off between the number of RSUs and the connectivity of the bus system with the infrastructure.

Note that there is a body of literature that addresses a related, but very different problem of locating sensors (magnetic loops, acoustic devices, cameras), and not communication devices that interact with each other, which is our subject. For references, see Danczyk and Liu (2010) and Li and Ouyang (2012).

In the sensor location problem, sensors located at different points of the network detect vehicles and measure origin–destination flows for a number of O–D pairs. The distance between vehicles, for example, is of no interest in this case. Also, the sensors are deployed in such a way as to optimize the vehicle counting, and sensors work in pairs, usually (since the origins and destinations of the vehicles need to be identified). Also, there is no need to identify each vehicle, because it is only the number of vehicles what is of interest. Furthermore, each vehicle does not need being identified and there is no communications other than a binary state (detected–not detected).

In our problem, buses are being dispatched at regular time intervals, but they tend to group together after a while. Precise monitoring of their individual positions and instructions to the drivers are needed to avoid the problem. The main issue is communications between bases and vehicles, through RSU's, possibly through a second vehicle. The interaction is not only between a vehicle and a sensor, but it could be between a vehicle and an RSU through a second vehicle, which makes critical the probabilistic study of the vehicles and their mutual distance. In the sensor case, there is no need of such study.

Because of these differences, the approaches used for sensor location are not applicable to the location of RSU's, especially if there is going to be communications between vehicles.

The remainder of the paper is organized as follows. In Section 2, we describe the communications model used for the V2I network. We analyze two different scenarios, the first using the unit disk communication model (Panichpapiboon and Pattara-Atikom, 2008; Sharif-Nassab and Ashtiani, 2012) and the second using the log-normal shadowing model (Rappaport, 2002) for the V2I communications channel. The mathematical formulation of the problem is presented in Section 3. Section 4 presents an evaluation of the proposed methodology, applied to a case study. Conclusions and further research are discussed in Section 5.