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Efficient message delivery in hybrid sensor and vehicular networks based on mathematical linear programming☆

Malika Sadou*, Louiza Bouallouche-Medjkoune

LaMOS Research Unit, Faculty of Exact Sciences, University of Bejaia, 06000, Algeria

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ABSTRACT

In this paper, we address the timely message delivery problem in Hybrid Sensor and Vehicular Networks (HSVNs). We formulate the problem as a bi-objective binary linear program with twofold goals: (1) to ensure real-time and accurate delivery of sensed information from roadside nodes (roadside units (RSU) and sensor nodes) to the sink, and (2) to extend the network's lifetime by inciting the roadside nodes to essentially perform sensing tasks and to act as relay nodes only when needed (e.g. network disconnections, low density of vehicles, etc.). The proposed linear programming model has been tested on several network topologies, and the experimental results have shown that small and medium size problems can be resolved in reasonable time.

1. Introduction

Nowadays, Vehicular Ad hoc Networks (VANETs) are considered as one of the most prominent technologies in Intelligent Transportation Systems (ITS). This emerging technology is becoming an attractive topic for both academic and industrial communities because of its promises in improving road safety. VANETs, which are considered to be a special class of Mobile Ad hoc Networks (MANETs), are composed of highly mobile vehicles and sparsely deployed roadside units. In VANETs, vehicles communicate with each other via Vehicle to Vehicle (V2V) wireless communication, and with roadside nodes via Vehicle to Infrastructure (V2I) communication [1]. The major purpose of these networks is to ensure road safety and to cope with the increasing statistics concerning vehicle crashes [2]. Nevertheless, VANETs suffer from severe limitations such as frequent network disconnections due to the high mobility (and sometimes low density) of vehicles, and sparse deployment of RSUs. To overcome these restrictions, integrating a Wireless Sensor Network (WSN) in a vehicular environment is proposed as an efficient solution to enhance the connectivity and the reliability of the system, as well as to ensure the surveillance of roads [3]. In such hybrid network, sensor nodes can be deployed densely along the two sides of the road to sense traffic conditions. The collected data by sensor nodes can be delivered to the sink using vehicles as relaying nodes. Thus the drivers can benefit from the received data, especially by warning messages to accommodate their behaviours so that to avoid danger.

In this work, we have investigated two important QoS metrics in hybrid sensor and vehicular networks which are end-to-end delay and energy consumption. Road safety application imposes a timely delivery of event notifications due to its sensitive nature. In fact, the detected data by roadside nodes should be timely delivered to the sink. Furthermore, the energy

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* Corresponding author.
E-mail address: malika.sadou142@gmail.com (M. Sadou).

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consumption of deployed sensor nodes should be minimized in order to prolong the network's lifetime. To deal with these challenges, we have proposed in this paper a new bi-objective linear programming model with twofold aims which are minimizing the message delivery delay and decreasing the financial cost of the system. At the best of our knowledge, it is the first time that mathematical linear programming is involved in addressing the problem of timely delivery messages in hybrid sensor and vehicular networks.

The remainder of this paper is organized in the following way. Section 2 gives an overview of previous proposed solutions for optimizing both the end-to-end delay and the financial cost in vehicular and wireless sensor networks. In Section 3, we define our system design and we describe the studied problem. In Section 4, we present the proposed bi-objective model. Section 5 exhibits the obtained experimental results. Finally, Section 6 summarizes and draws conclusions.

2. Related works

In this section, we give an overview of the existing research on routing approaches in vehicular and wireless sensor networks. We focus mainly on those that are based on mathematical modelling with the aim of decreasing end-to-end delay and minimizing the energy consumption in order to improve road safety. First, we begin with some frameworks designed in hybrid sensor and vehicular networks. In this setting, Djahel and Ghamri-Doudane [4] proposed an HSVN framework to ensure an effective transmission of detected information related to road dangerous events toward passing vehicles. This scheme takes into account the low battery of sensor nodes. Thus, a scheduling mechanism to switch the status of sensor nodes between sleep and active has been established. Qin et al. [5] proposed a hierarchical architecture which combines VANET and WSN. Both of sensor and vehicular nodes are partitioned into groups, where each cluster is managed by a Cluster Head (CH). Each sensor node transmits the collected data to its CH which is responsible of aggregating data and forwarding it to vehicles/RSUs in its transmission range. The vehicles use a geo-cast protocol to forward data to the sink. This approach aims to preserve the energy consumption in WSN deployed along a road. For this reason, a sensor node wakes up when a vehicle is approaching to its communication range; otherwise, it remains in sleep mode. Several works which dealt with how to select the next forwarding node for disseminating messages were proposed in the literature. The algorithm designed by Xian et al. [6] aims to disseminate efficiently the emergency messages and to minimize the unnecessary transmissions. Many other works in this scope have been presented by Chaqfeh et al. [7].

Based on a simple Integer Linear Programming (ILP), a new traffic controller has been proposed by Ghaffarian et al. [8]. This solution dealt with safe driving patterns crossing a junction by maximizing the number of passing vehicles across an intersection and minimizing the tolerated delay for vehicles. Chen et al. [9] addressed the MSNs (Mobile Sensor Networks) scheduling issue with the purpose of solving the energy consumption problem. Due to the high time complexity of their formulated program (ILP), the authors proposed a greedy algorithm for its resolution. This procedure allows mobile sensor nodes to transmit the real-time sensed data with lower energy consumption.

Ant Colony Optimization (ACO) has recently gained a great deal of attention and many algorithms designed for VANETs have been inspired by this meta-heuristic. In this framework, Correia et al. [10] proposed bio-inspired procedures which aim to take advantage of information disposable in the vehicular network such as vehicle's positions and velocity. The authors adapted the proposed procedures to the Dynamic MANET On-demand (DYMO) routing protocol. Based on the same approach (ACO), the contribution proposed by Kazemi et al. [11] intends to enhance the reliability of routing protocol by selecting the highest reliable routes in VANET. Initially, the authors modelled the network topology as a graph, and then they solved it using the optimum objective function. Silva et al. [12] proposed a multi-objective heuristic algorithm based on ACO to find the best route in terms of the number of nodes and the lowest probability of disconnection. Li and Boukhatem [13] proposed a new protocol named VACO (Vehicle Ant Colony Optimization). It is an adaptive QoS routing protocol based on ACO optimization which aims to establish and maintain the best route from a source node to the nearest target intersection in terms of latency, bandwidth, and delivery ratio. The quality of each road segment is estimated by the pheromone routing tables. Choi et al. [14] proposed a novel Distributed Intelligent Traffic System (DITS). This approach has been inspired by swarm intelligence to find a route with less traffic before intersection, with the objective of reducing travel time. Eiza et al. [15] proposed a VANET routing algorithm called SAMQ (Situation-Aware Multi-constrained QoS) which consists of employing situational awareness concept and ant colony system to route data between vehicles. Lin and Deng [16] studied the problem of minimizing the overall cost of wireless sensor and roadside nodes deployed along the two sides of road. In order to ensure the coverage and the connectivity of the whole road, the authors have firstly formulated the problem as an integer linear program and then a particle swarm optimization approach has been applied.

On the other hand, the concept of clustering is significantly applied to deal with the stability and robustness problem in VANET. In this setting, a clustering algorithm for vehicular network in highways environment has been designed by Hadded et al. [17]. In order to optimize this algorithm and to achieve three goals, which are: providing robust cluster structure, maximizing data delivery rate, and minimizing the clustering overhead, a multi-objective problem has been defined and addressed by a genetic algorithm. Based on an evolutionary algorithm and a swarm intelligence approach, Toutouh and Alba [18] applied two parallel multi-objective optimization algorithms to find a best configuration of AODV (Ad hoc On-Demand Distance Vector) algorithm in VANET which leads to maximizing the reliability and minimizing the communication delay. In another context, Saleet et al.[19] addressed the transfer of data between intersections and proposed a solution which intends to select efficiently road intersections, to ensure the network connectivity, and to satisfy QoS constraints in tolerable delay. To achieve these goals, they mathematically formulated these metrics as a constrained optimization problem which

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