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Green vehicle traffic routing system using ant-based algorithm

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ABSTRACT

Vehicle traffic congestion leads to air pollution, driver frustration, and costs billions of dollars annually in fuel consumption. Finding a proper solution to vehicle congestion is a considerable challenge due to the dynamic and unpredictable nature of the network topology of vehicular environments, especially in urban areas. Vehicle Traffic Routing Systems (VTRSs) are one of the most significant solutions for this problem. Although most of the existing VTRSs obtained promising results for reducing travel time or improving traffic flow, they cannot guarantee reduction of the traffic-related nuisances such as air pollution, noise, and fuel consumption. Hence, in this paper, we present a green VTRS that reduces fuel consumption and consequently CO_2 emissions via ant-based algorithm combined with fuel consumption model. This VTRS is an Ant-based Vehicle Congestion Avoidance System (AVCAS) that uses Signalized Intersection Design and Research Aid (SIDRA) fuel consumption and emission model in its vehicle routing procedure. This approach is called AVCAS+SIDRA which utilizes various criterion such as average travel time, speed, distance, vehicle density along with road map segmentation to reduce fuel consumption as much as possible by finding the least congested shortest paths in order to reduce the vehicle traffic congestion and their pollutant emissions. The proposed approach is evaluated and validated through simulation environment and tools (i.e. NS-2, SUMO, TraNS). Experimental results conducted on three different scenarios (i.e. various vehicle densities, system usage rates and accident condition) considering average travel time, travel speed, travel distance and fuel consumption as evaluation metrics. The obtained results show that the AVCAS+SIDRA outperforms the existing approaches in terms of average travel time, average travel speed and fuel consumption rate, by an average of 25.5%, 19.5% and 17%, respectively. Consequently, our proposed green VTRS alleviates energy consumption as it is not only becoming scarce and expensive but also causing a dramatic climate change and emission.

1. Introduction

Over the last decade, vehicle population has dramatically increased all over the world. This large number of vehicles leads to a heavy traffic congestion, lots of accidents, air pollution, high fuel consumption and consequent economic issues (Narzt et al., 2010). In 2010, the American people faced a lot of difficulties due to vehicle congestion which forced their government to spend 101 billion dollars on the purchase of extra fuel (Schrank et al., 2012). Based on a report by Texas A&M Transportation Institute, it is estimated that fuel consumption will rise up to 2.5 billion gallons (from 1.9 billion gallons in 2010) with a cost of 131 billion dollars in 2015 (Schrank et al., 2012). In addition, according to RACQ Congested Roads report (Spalding, 2008), fuel consumption, CO2 and greenhouse gases emissions, long travel time and accidents are both direct and indirect results of vehicle traffic congestion and rough (vs. smooth) driving pattern. Idling, driving, accelerating and decelerating are four main states which are used by drivers who want to travel from a source to a destination (Barth and Boriboonsomsin, 2009). These four states will be happened due to various conditions like behavior of the drivers, type of the roads, level of the traffic and weather conditions. Based on results in (Barth and Boriboonsomsin, 2009; Frey et al., 2003) decelerating and accelerating had the highest CO_2 emissions and fuel consumption among the other states. In addition, cars engine consumes more fuel in idle state compared to driving state. Therefore, CO_2 and greenhouse gases emissions can be decreased by providing smooth trips which include fewer stop and go driving state as well as lesser stopping times. Hence finding effective solutions with reasonable cost for congestion mitigation can reduce the fuel consumption and minimize the pollutant emission and preserve the environment clean and green (Salvi et al., 2013; Ahmed et al., 2013; Bakhouya et al., 2011).

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Building new high capacity streets and highways can mitigate some of the aforementioned problems. Nevertheless, this solution is very costly, time consuming and in most of the cases, it is not possible because of the space limitations. In addition, research on finding alternative efficient fuels needs more time and effort to become a reality (Van Mierlo et al., 2004; Poulton, 1994). Besides, the vehicle manufacturers such as Honda, Toyota, and Nissan have made some efforts to enhance vehicle design and engineering to promote fuel efficiency, economical factors, and environmentally friendliness. Green technologies have concentrated on the interior of vehicles (i.e., in-vehicle enhancements). For example, car companies conduct research on how to make economically and environmentally friendly car engines. Hybrid and full electric vehicles are some examples of these efforts (Demestichas et al., 2011; Jiang et al., 2011). On the other hand, optimal usage of the existent roads and streets capacity can lessen the congestion problem in large cities at the lower cost. However, this solution needs accurate information about current status of roads and streets which is a challenging task due to quick changes in vehicular networks and environments. Intelligent Transportation System (ITS) (Dimitrakopoulos and Demestichas, 2010) is a new emerged system which integrates network-based information (e.g. vehicular ad hoc networks (VANETs), wireless sensor network) and electronic technologies (e.g. sensors, cameras) with transportation technologies (Martinez et al., 2010; Jabbarpour et al., 2014a,d). ITS covers a wide variety of techniques and technologies such as Vehicle Traffic Routing Systems (VTRSs), electronic toll collection system (ETCS), and Intelligent traffic light signals (TLSs) to reduce the fuel consumption and CO_2 emission. A common scenario for an ITS application includes collecting data using some type of sensors and then distributing the data among the communicating nodes/entities (a node can be a road-side unit, not necessarily a vehicle). The resulting decision is based on specific algorithms that lead to meaningful information for drivers (e.g., the shortest, fastest, less congested path, which can save a significant amount of fuel as the car need not idle along the more congested route). Many applications of ITS exist, including vehicular traffic congestion avoidance, travel time reduction, vehicular traffic density estimation, and energy-saving (Papadimitratos et al., 2009; Kuriyama et al., 2007).

The ITS technologies promote the reduction of fuel consumption with two aspects, that is, first to reduce congestion that maintains each vehicle to optimal speeds and secondly to provide alternative paths with shortest time duration instead of shortest path distances to the driver for a green fuel efficient path (Tsugawa and Kato, 2010). TLS and VTRS are two most popular solutions of ITS for fuel consumption and CO_2 emission problems (Alsabaan et al., 2013). These solutions are discussed in related work section. However, considering the cost and time limitations, VTRS is a better solution than TLS. Various VTRSs are proposed in Desai et al. (2013), Wang et al. (2013), Pan et al. (2012), Tatomir and Rothkrantz (2004), and Kponyo et al. (2012), but among them, using Multi Agent System (MAS) is reported as a promising and one of the best approaches for dynamic problems, specially, vehicle routing problem (Kponyo et al., 2012; Sur et al., 2012). In addition, ant agents have proven to be superior to other agents in Bonabeau et al. (1999), Dhillon and van Mieghem (2007), and di Caro and Dorigo (2011). Ant algorithm was initially introduced by Dorigo (1992) in PhD thesis and was inspired by the natural behavior performed by ants in finding food resources. In this natural behavior, ants release a chemical liquid, called pheromone, on their traversed paths based on the quality of the food resource found while moving from their nest to the food source and vice versa. This pheromone trail helps other ants to find the food resources by sniffing the pheromone. The pheromone intensity increases (pheromone reinforcement) by ants or decreases (pheromone evaporation) over time in order to increase the probability of finding food resources or new paths. A comprehensive overview of ant-based VTRSs can be found in our previous study (Jabbarpour et al., 2014c).

In this paper, we integrate our recently proposed AVCAS approach (Jabbarpour et al., 2014b) with SIDRA fuel consumption and emission microscopic model (Akcelik and Besley, 2003; Akçelik et al., 2012), called AVCAS + SIDRA, in order to examine its impact on fuel consumption, number of stopped vehicles due to traffic congestion, vehicles' travel distance, speed, time and consequently CO_2 emission. In other words, AVCAS + SIDRA efficiency regarding green environment issues is evaluated in this paper. The main goal of AVCAS + SIDRA includes proposing the shortest path with the least congestion and travel time, lowest fuel consumption as well as higher vehicle speed. Moreover, non-recurring congestion (e.g. accident, working zones, weather conditions) are also implicitly considered and handled in AVCAS + SIDRA. It periodically computes n shortest paths, where n is the number of alternative paths, based on various metrics for different Origin Destination (OD) pairs instead of computing these paths for each vehicle and re-routes the vehicles through the least congested shortest paths based on their destinations. By considering SIDRA model, air pollution and fuel consumption are also decreased by this system.

The rest of this paper is organized as follows: Section 2 discusses the impact of vehicle speed on fuel consumption along with existing green traffic control and routing systems. AVCAS +SIDRA and its phases are presented in Section 3, while Section 4 includes the simulation results and system evaluation. Finally, Section 5 concludes the paper and suggests the direction for future research.

2. Green intelligent transportation systems

During last four decades, urban traffic control (UTC) systems based on traffic light signals (TLSs) have attracted researchers and get attention of automobile industry. Complex mathematical formulas and models are used in most of the existing UTC approaches in order to tune various parameters of TLS such as cycle duration, offset, green split and it sequence (Sattari et al., 2014). Split Cycle Offset Optimization Technique (SCOOT) (Robertson and Bretherton, 1991) and the Sydney Coordinated Adaptive Traffic (SCAT) (Sims and Dobinson, 1980) are the most well-known examples of this kind of UTC systems. In these systems, one or two detectors are placed at each street of intersections for counting the number of vehicles that arrive to specific controlled intersection. Accurate traffic information is not achievable whenever queue size of vehicles grows beyond the distance between two detectors. Distinction between intersection stops and high traffic flows are difficult task in these systems because they use mathematical models (Li and Shimamoto, 2012; Al-Sultan et al., 2014). Prakash and Tiwari (2011) provided a new counter based method as well as best pass selection algorithm for managing the traffic problem and decreasing the travel way and fuel consumption. However, it still suffers from aforementioned problems. Green ITSs are divided into two categories, namely adaptive TLSs and Green VTRSs, and are discussed in following subsections.

2.1. Traffic light signals

Various adaptive or intelligent TLS systems that use wireless communication between vehicles and Road Side Units (RSUs) at intersections are introduced in the literature (Gradinescu et al., 2007; Maslekar et al., 2011; Sanketh et al., 2010; Tubaishat et al., 2007). The target of the adaptive TLS system is the reduction of vehicles congestion queue size, waiting time and stop-and-go mode at behind the traffic lights and makes the trips smoother (Shamshirband, 2012). Vehicles in a stop-and-go running consume more fuel and emit more pollutants than constant speed driving.