Algorithms for Energy-Efficient and Collaborative Vehicle Scheduling in Highway-Based Vehicular Networks

Deepti Negi,
Asst. Professor, SOC (School of computing),
GEHU-Dehradun Campus
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Abstract: Road safety, real-time traffic management, location-aware advertising, environment monitoring, connection in distant regions, etc. are just some of the many uses made possible by cooperative vehicular networks. In order to efficiently disseminate data to cars beyond the coverage of a Road Side Unit (RSU) positioned along the road side, vehicles interact with one another and the RSUs. In order to provide for cars that have lost connection with the RSU, it uses passing vehicles as store-carry forwarders (relays). However, the RSUs used along highways are power constrained, therefore they work to minimise their use in downlink communications to relay trucks. As a result, in a highway automobile network, enhancing data transmission is crucial while decreasing RSU energy usage, data delivery latency, and reaction time. Buffering delays at the RSU are caused by the constant delivery of task data to buffering with limited capacity, despite the fact that energy harvesting devices extend RSU lifespan. For this reason, under time pressure from tasks, a dynamic system for allocating power is required. To further complicate matters, reducing the typical response time of activities requires immediate planning of fog vehicles for energy-efficient dumping of jobs inside RSU coverage.

Keywords: Highway vehicular networks, energy efficiency, minimum cost flow graph,clustering, end-to-end delay, Auction theory, buffering delay

Introduction

Vehicular ad hoc networks (VANETs) and other kinds of wireless communication have allowed for the creation of smarter, more secure transportation systems that can provide features like real-time traffic updates, in-car media, and hyper-specific advertising[1]. Through the use of On-Board-Units (OBUs) and Road Side-Units (RSUs), Vehicle Area Networks (VANETs) allow cars to connect with one another and with wireless access points along the road. The RSU is a practical piece of roadside infrastructure that allows cars to pass through safely and quickly. Road VANETs (vehicular ad hoc networks) may measure the cars' constant velocity [2]. In addition, the vehicles' high rates of speed mean they spend just a brief period of time inside RSU range. One control channel (CCH) and six service channels (SCH) are available in the 5.9 GHz range for usage with Designated Short Range Communication (DSRC) from the Federal Communications Commission. The transmission of control (CCH) and utility (SCH) messages is separated into different communication channels. Additional subcategories of VANET connection options include Institutional to Vehicle (I2V) & Vehicle to Vehicle (V2V). These channels of interaction provide the provision of services for cars in motion that are either directly connected to safety (collision warning, real-time traffic, etc.) or indirectly related to safety (weather information, location-aware advertising, etc.). When in vicinity of the RSUs, vehicles equipped with in-vehicle to vehicle (I2V) communication may access the web. Vehicles may accelerate quickly, meaning they might depart RSU before all data is retrieved.

Target vehicles are those that leave the coverage area of an RSU while still in need of data. Store-and-forward automobiles (relays) with vehicle-to-vehicle (V2V) forwarding allow RSUs to continue sending data to a recipient vehicle even after it has moved out of range. It is difficult to equip RSU with direct connected power since electricity supply connections are few at outlying highway sites. RSUs may be powered by renewable resources like as wind, solar, etc. According to a deployment study conducted by the United States Department of Transportation [3], by 2050, solar energy providing will account for a projected 63% of RSU expenditures and more than 40% of rural highway roadside infrastructure would be solar-powered. RSUs deployed in rural areas often include rechargeable batteries supported by energy harvesting technologies [4]. The monthly cost of providing electricity to an RSU is heavily influenced by its typical monthly energy use [5]. This is due to the fact that the RSU's energy usage is very sensitive to its distance from the vehicle[6]. Sending a downlink (RSU-to-vehicle) message to a vehicle in close proximity requires less RSU power than sending the same message to a vehicle on the edge of the RSU's range. Figure 1 shows that at time t1, the vehicle v is d1 clock ticks from the RSU, and at time t2, the vehicle v is d2 clock ticks from the RSU. The RSU would like to make downlink contact with vehicle v at time t1 rather than t2 since d1 is less than d2. However, a careless selection of neighbouring vehicles might have a detrimental influence on the efficiency of the system in terms of data transfer, end-to-end latency, response time, etc. The optimal scheduling of vehicles in RSU coverage is a critical issue because to the trade-offs that must be made between RSUenergy consumption and other aspects of the system's information dissemination service.

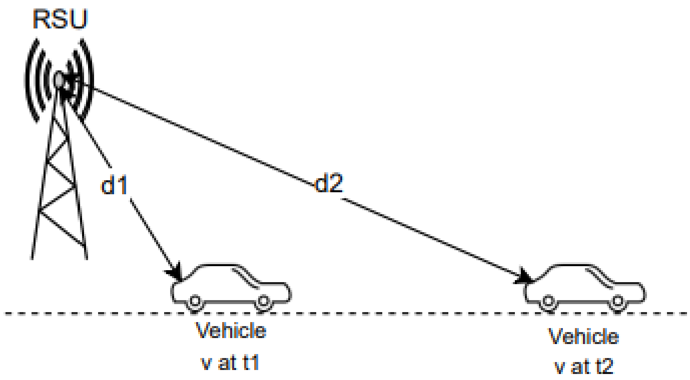

Figure 1: Downlink communication scenario

More dependable data services (such as big file downloads, sensor data transmission, etc.) may be attained by the effective use of I2V and V2V communications' synergistic effects [7, 8]. In highway sites, RSUs are unable to offer seamless radio coverage owing to the high installation cost of the vehicle infrastructure, leaving uncovered region or outage area between the neighbouring RSUs [9]. Due to factors such as low I2V bandwidth, high vehicle mobility, and high data consumption, RSUs may be unable to fulfil requests from cars within RSU coverage [10]. Therefore, vehicles have an unmet information need while venturing into the unknown. Target cars are those that are the object of an attack. However, with the help of cars passing by, called relay vehicles, the target vehicles may obtain the unserved (residual) data. When establishing V2V linkages with a destination vehicle, these relay vehicles use the store-carry-forward [12] method to provide service. However, optimising data transmission services and cutting down on energy use both rely on the timely scheduling of relay trucks. As discussed before, the restricted radio range and high deployment cost of RSUs leaves gaps in coverage between adjacent RSUs. Some RSUs, in particular, may be located along rural highways far from the grid's power sources or its backbone network (which links individual RSUs).

As a result, a source RSU deployed in a remote area must rely on energy collecting technology and rechargeable batteries[13]. In addition, storecarry-forward vehicles or relays are required to transfer the workloads produced by the applications operating in the source RSU area to a nearby destination RSU (that has a high-end computing server and links to direct grid power). However, developing an effective algorithm for scheduling relay vehicles in such a dynamic setting has significant difficulties. First, the source RSU has no way of knowing which cars will arrive when, so it must plan the best available relay vehicles in its coverage area at the moment. Second, the storage capacity of RSU-equipped rechargeable batteries is low; as a result, an efficient power distribution technique is necessary for making good use of the energy that has been stored. Third, the source RSU has no say over when task data will arrive, which may lead to buffer instability and a steady buildup of back-logged data. To optimise data transmission to the target RSU while minimising both energy usage and buffering latency, a dynamic power allocation approach is required.

Nearest Neighbour Forward Approach

The Nearest Neighbour Forward (NNF) proposal uses a car's closeness to renewable energy sources to choose which automobiles it will use as data forwarders for relay vehicles. The nearest neighbour forwarder is a vehicle that is multi-hop neighbours with both the RSU and a relay vehicle. Using the NNF technique, each relay vehicle is paired with a forwarder vehicle depending on its closeness to the latter within a certain time window. If r is a relay, then NNF(r) is the nearest neighbour forwarder of r. After that, it calculates the enthalpy required to transform RSU into NNF(r), where r is a constant. The scheduler (MCF) receives NNF's energy use costs as an extra input. By combining the MCF with the NNF, we get the MCF-NNF notation.

Max-weight relay vehicle scheduling

To choose relay vehicles that can complete their tasks on time, a relay scheduling problem is defined. To address this problem, the authors implement a method for selecting relay cars with the highest possible data rates (determined by the dynamic power allocation algorithm) and then using I2V communication to send the contents of the RSU's buffer to the selected relay vehicles. The effectiveness of the suggested algorithms for buffering and scheduling has been shown via a simulation study. It has been shown that the suggested technique significantly increases the system's average data delivery rate, network lifetime, and buffer stability.

Fuzzy reinforcement learning for energy efficient task offloading from RSU to mobile fog vehicles

Tasks in Vehicular Fog Computing (VFC) are scheduled in this study in a way that minimises energy use while yet accommodating for delays. By functioning as mobile fog nodes that enable efficient use of computing resources, the VFC brings fog computing to traditional vehicular networks. This computational model makes use of application execution and workload distribution over mobile fog nodes while taking latency into account. The RSUs used on rural routes are often solar-powered and equipped with rechargeable batteries[23]. For effective work allocation to possible fog vehicles, the RSU offers third-party scheduling services. However, scheduling fog cars in VFC in an energy-efficient manner is necessary for extending the network's lifetime and reducing the load on its batteries. The VFC relies on a stationary RSU to delegate tasks to fog vehicles and provide supplemental local computation. Finding possible fog cars in real time using intensive search approaches becomes more challenging as the number of vehicles under RSU coverage grows. As a result, a system based on reinforcement learning is proposed in this study to detect possible fog vehicles throughout each time period. The suggested technique employs a greedy heuristic based on fuzzy logic to speed up the learning process, which is otherwise slowed down by the huge action space and high dimensionality inherent in the problem. What follows is a description of the work's most significant contributions. Introduce a framework for vehicular fog computing (VFC) to offload work from real-time applications in smart cities located near rural routes.

• To effectively allocate tasks among fog vehicles while adhering to time and resource restrictions, we may formulate the optimisation issue as an Integer Linear Programming (ILP) problem.

• In order to allocate jobs to fog vehicles in an effective manner while also conserving energy, we propose a Fuzzy Reinforcement Learning (FRL) strategy in which a Fuzzy logic-based greedy heuristic is fused with an on-policy reinforcement learning (i.e., SARSA). The FRL does more than just speed up the learning process; it also helps choose the best vehicles to use in fog so that you can save energy and react faster. This paper introduces a greedy heuristic and reinforcement learning approach to scheduling fog nodes in real time, with the goals of increasing long-term reward and accelerating the learnt result, respectively. Extensive experimental findings reveal that the suggested algorithm outperforms its competitors by 46.73 percent in terms of energy usage and 15.38 percent in terms of reaction time.

Literature Review

Xian Guo et.al.,(2020) Named Data Network (NDN) has caused great concern in the VANET community due to its content-centric approach, which identifies stuff rather than the host. However, there are a number of challenges specific to NDN-VANET integration, including user and service provider mobility, the broadcast storm problem, and others. In this paper, we provide a Bayesian statistics-based Receiver Forwarding Decision (BRFD) technique to mitigate the broadcast storm caused by interest packets in NDN-VANET. As part of the BRFD, vehicles must use Probabilistic decision theory to relay an interest packet based on the current network conditions as learnt from neighbour contact. However, a receiver-forwarding decision conflict may also develop via BRFD if many vehicles forward the same packet at the same time. For this reason, BRFD has an automatic "back-off" function. Multiple trials show that the BRFD approach is superior to both the probability-based forwarding system and the "bread crumb" routing methodology.

P. Ramkumar et.al (2020) Using a combination of VANETs and the cellular networks of the larger transportation system, the authors of this paper discuss a hybrid intelligent transportation system (ITS) that allows for instantaneous, effective communication within

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vehicles, roadside assistance systems (RSUs), and a vehicle-traffic server. As a consequence, the proposed real-time path-planning algorithms not only improves the geographical coverage of the roadways, but also reduces the typical trip cost of evacuating cars stuck in traffic. Comparing the suggested route-planning technique to the baseline of regular distributed path planning, the NS2 system-level simulations confirms that the former quickly reaches spatial equilibrium. Throughput as well as latency characteristics of the hybrid VANET are evaluated, providing insight into how congestion in IT systems might be alleviated.

Tarandeep Kaur Bhatia et.al (2020) The potential of vehicle ad-hoc networks of networks (VANETs) to increase driver safety has made them a prominent topic of study. We examine the novel contributions made with the aid of mobility theories and technologies for VANETs. Human efforts starting with network development and concluding with the selection of a casual tour transform the underlying map into an SUMO network. The focus of this study was to summarise the most important concepts and procedures used in VANET-based studies. Researchers have found that although VANET does allow cars to connect, doing so and communicating with nodes in real time is a difficult task. This has led to the development of a plethora of separate VANET communication simulation systems, such as NS-2, NS-3, OMNET++, GloMoSiM, SNS, JiST/SWANS, and many more.

Results and analysis

In this research, we look at the outcomes of using the proposed approach (FRL) vs certain alternatives (DTA DP, Fuzzy, RMS, and FCFS). For this evaluation, we varied a variety of settings, such as the number of vehicles in the play area, the nature of the work, and the timing of the assignments.

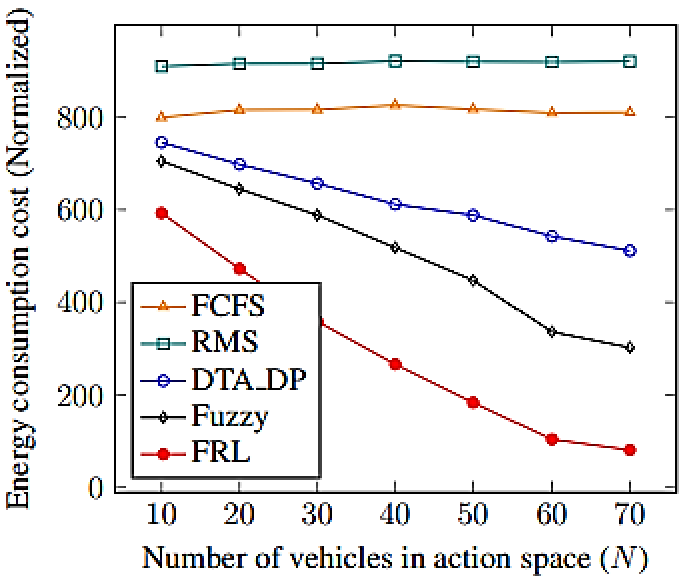

Figure 1: Number of vehicles and energy consumption

A series of experiments are carried out to ascertain the impact on RSU energy consumption by varying the number of automobiles under RSU coverage (as seen in Fig. 1). To review, we assume exponential RSU coverage and use a Poisson process to describe vehicle arrivals. The range of possible vehicle speeds is tightly contained by the range [15m/s, 25m/s]. Increases in the number of vehicles covered by RSUs have been shown to benefit the proposed FRL technique, DTA DP, and Fuzzy. This is that there is a higher probability that another automobile will be near RSU when there are more vehicles in the area of conflict. Because of this downlink communication with surrounding fog vehicles reduces RSU energy consumption, and the cost of operating an RSU lowers linearly with increased action space. It is shown, however, that the energy cost for RMS and FCFS is constant throughout all action spaces. This is because the RMS gives fog vehicles lower priority the longer they remain in the RSU zone ("dwell time"). There are more cars in the action zone than ever before, but they are still clustered at the RSU's terminal. Even if the very first vehicle to arrive is well on the edge of the RSU's departure zone, the FCFS will still choose it. The high downlink transmission cost from the RSU to the furthest vehicles negatively impacts the energy efficiency of the RMS and FCFS. Using the proposed FRL method results in a 48.27% decrease in total energy expenditure when when compared with both Fuzzy and DTA DP (see Fig. 2). When there are several vehicles within RSU range, the FRL technique has a lower cumulative energy footprint over time.

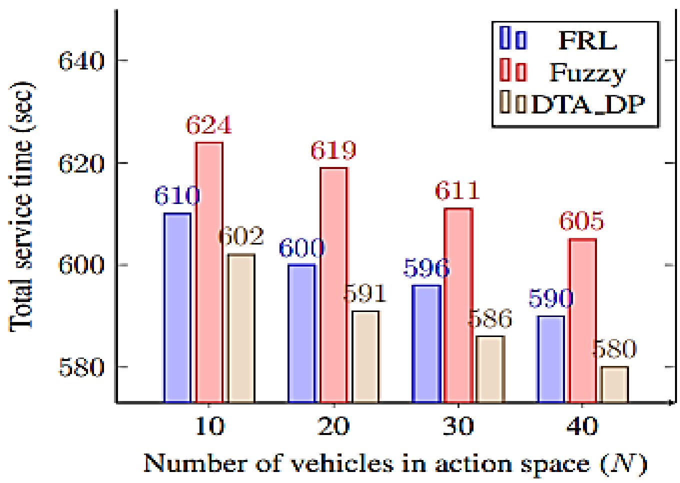

Figure 2: Number of vehicles and total service time

It has also been empirically studied how much longer jobs take to finish when distributed in fog. A comparison of the proposed FRL with two other scheduling systems is shown in Fig. 2, where x is the number of automobiles under RSU coverage and y is the total amount of seconds spent on task service. As previously mentioned, the amount of "service time" required to complete missions when driving a fog vehicle. Fog vehicle processing rates are assumed to be normally distributed between [10, 100] cycles/sec, with a need of 500 cycles per operation. The least amount of time a fog vehicle is required to do a duty is 5 seconds, with a maximum of 50 seconds. It has been observed that a single fog vehicle requires at least 500 seconds of service time to cover 100 consecutive time slots. Figure 2 demonstrates that DTA DP has a shorter total service time compared to both the proposed FRL and Fuzzy. Figure 4 demonstrates that DTA DP, despite its improved performance in terms of service time as a consequence of its selection of fog vehicles with the shortest completion time, does not yield superior results in terms of energy usage. Figure 5 shows that the largest difference between DTA DP and the predicted FRL is less than 1.8%. It is also shown that the total service time of tasks lowers when more cars reach the action area. This is because scheduling algorithms have greater flexibility when there are more fog vehicles accessible within the RSU's coverage area. However, the primary goal of this project is to decrease RSU power consumption by the use of fog vehicles to complete tasks under rigorous operating time and deadline criteria. Since minimising power usage is paramount, we propose using FRL instead of DTA DP or Fuzzy Logic..

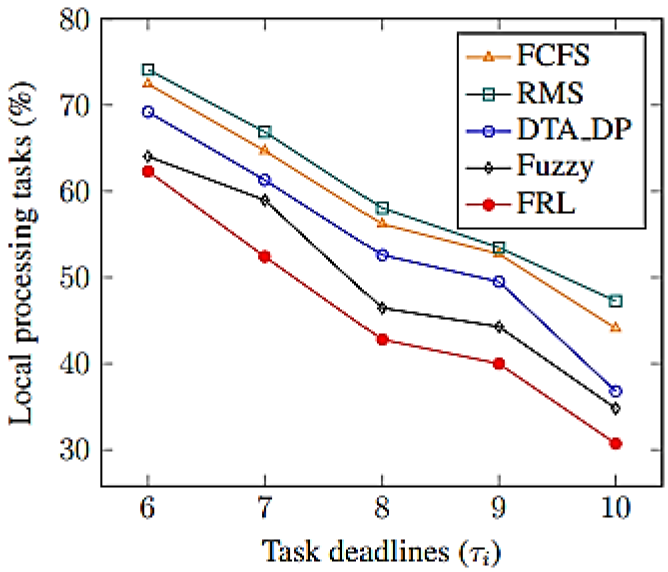

Figure 4: Task deadlines and local processing tasks

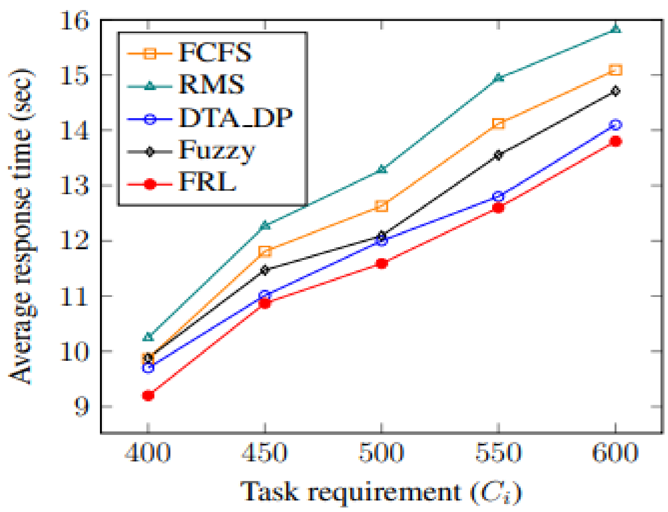

Figure 5 Task requirements and Average response time

Conclusion

This paper focuses on an intelligent transportation system that was created with Indian four-lane highways in mind. The left-hand-traffic system is used on these routes. The posted speed limits for the inside and outside lanes are 90 and 60 kilometres per hour, respectively. The speed limits and other features of this system may be tailored to the varying widths of India's highway routes, from two lanes to eight. Furthermore, this approach may be adapted to the left- and right-hand traffic systems used in different nations throughout the world. This system's forecast accuracy is now around 92% over a variety of highway road situations, and it has room to improve. By selecting backup routing pathways for messages, this system may continue to function even if signals are lost or a connection is broken. This Intelligent Transport System has more potential due to the addition of delay tolerant network characteristics that will allow for faster message transmission. A first-rate, cutting-edge transport infrastructure is necessary for the successful implementation of such a smart system. The contemporary civilizations need this form of smart intelligent transport system for creating safer and more efficient traffic, despite the fact that deployment and maintenance of such an infrastructure is complex and needs more investment in developing nations like India.

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