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Dynamic Management of Traffic Signals through Social IoT

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Abstract

Traffic congestion is a major threat to transportation sector in every urban city around the world. This causes many adverse effects like, heavy fuel consumption, increased waiting time, pollution, *etc.* and pose an eminent challenge to the movement of emergency vehicles. To achieve better driving we proceed towards a trending research field called Social Internet of Vehicles (SIoV). A social network paradigm that permits the establishment of social relationships among every vehicle in the network or with any road infrastructure can be radically helpful. This holds as the aim of SIoV, to be beneficial for the drivers, in improving the road safety, avoiding mishaps, and have a friendly-driving environment. In this paper, we propose a Dynamic congestion control with Throughput Maximization scheme based on Social Aspect (D-TMSA) utilizing the social, behavioral and preference-based relationships. Our proposed scheme along with the various social relationship types allocates green signal to maximize the traffic flow passing through an intersection. Simulation results show that the D-TMSA outperforms the existing work by achieving high throughput, lowering the total traveling time and reducing the average waiting time to better the flow of traffic based on their social attributes with each other.

Keywords: Dynamic Traffic Control; Traffic Congestion Management; Social Internet of Vehicles (SIoV); Social Relationships

1. Introduction

The number of vehicles plying on the roads is growing rapidly with the increase in population. Nearly all the significant urban cities experience massive traffic during the peak hours. An unfortunate accident or a maintenance

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task on the road can lead to a massive hold-up and further setbacks to the movement of vehicles [1]. This traffic congestion incorporates social expenses like time delay, heavy fuel consumption, costs due to traffic accidents *etc*. Traffic signals play an important role in preventing the frequent disturbances to the traffic flows and increase in delays. Therefore, care must be taken for their effective management so as to improvise traffic congestion.

Social Internet of Things (SIoT) has surfaced after the integration of social networking notion in the Internet of Things (IoT) [2]. It is interdisciplinary in nature aimed making a connected smarter world. An instance of SIoT, called Social internet of Vehicles (SIoV) has emerged that socializes the vehicles, commuters and transportation infrastructure [3]. In a transportation system, while IoT establishes the network between the components (vehicles, commuters, roads, *etc*.), SIoT tries to socialize these components by establishing relationships between them [4].

The SIoV system deals with delivering different kinds of information to several stakeholders of the transportation system (drivers, passengers, *etc*.), like emergency information [5], receiving the On-Board Diagnostics (OBD) parameters from vehicles [6] *etc*. It also communicates with the Road Side Units (RSUs), that provides the traffic patterns and vehicular flow, for a safe and comfortable ride. This system utilizes social connections among the entities and communications between them to analyze the generated data that aids in traffic management. Generally, smart vehicles are furnished with cutting edge technologies in order to establish Vehicle-to-Vehicle (V2V) communications with the vehicles close-by. There also exists Vehicle-to-Infrastructure (V2I) communications where the vehicles communicate with RSUs to exchange meaningful information as mentioned earlier. These smart vehicles can form social relationships with RSUs and other vehicles [7].

In this paper, we employ the concept of SIoV which describes both the social interactions among vehicles and commuters to address the traffic congestion issue through dynamic management of traffic signals. The contributions of the paper is as follows:

1. A dynamic congestion control scheme through the use of various relationship types to increase the vehicle passing rate and enables smooth flow of the traffic.
2. To maximize the flow of non-conflicting traffic by structuring it dynamically.
3. Maximize throughput to control the traffic signals and increase the flow count.

The rest of this paper is organized as follows. Section 2 describes the relevant works that were carried out in the past to address the traffic congestion issue. Problem statement and background work to the proposed scheme are discussed in Section 3. The proposed system model is presented in Section 4. Implementation details along with the performance analysis is detailed in Section 5. Finally, contain conclusions in Section 6.

2. Related Works

In this section, we present the recent related works that address the traffic congestion issue. To augment the need of SIoT and SIoV towards the congestion problem, we review a few relevant works from these domains as well.

2.1. Traffic Congestion

Traffic congestion is a condition that usually occurs where the traffic of vehicles is greater than the capacity of the roadway. Rui *et al.,* [8] proposed a traffic congestion detection and quantification method based on vehicle clustering and fuzzy assessment. It uses the network environment, cluster head selection for cluster formation and maintenance process. Finally, fuzzy assessment is adopted to recognize the level of traffic congestion considering the average speed, road width, and average stop delay. Hu *et al.,* [9] proposed an Actual Urban Traffic Model (AUTM) for the prediction and avoidance of traffic congestion. It consists of three elements: (i) Map and Transfer (MT) conversion method, (ii) congestion-avoidance routing algorithm, and (iii) optimized spatial evolution rules. This work could explain the consideration of more pragmatic features in the proposed model and the size of the road networks that could be simulated. Menelaou *et al.,* [10] presented a continuous-time route reservation architecture to efficiently manage vehicle routing decisions to get rid of congestion. It utilizes earliest arrival time at destination in continuous time to create prediction methods to estimate more accurate time for navigation. The consideration of accidents in the model and rescheduling the vehicles on demand responding to the accidents should be formulated manually.

2.2. Internet of Things (IoT)

IoT is the augmentation of internet connectivity into everyday items and physical objects. Girau *et al.,* [11] presented a cloud based IoT platform called Lysis for the organization of Internet of Things applications. It addresses four noteworthy features, for example, social agents, Platform as a Service (PaaS) model, Social Virtual Object (SVO), and cloud storage. It fails to address the issue of task allocation between the real objects and the virtual correlative objects through runtime code infusion into the real devices, and substantial use-cases deployments. Sankaranarayanan *et al.,* [12] have implemented SVM machine learning algorithm for examining the data pattern and recognition of anomalies to prevent the issues on security protocols. This system does not explain about the application of reinforcement and unsupervised learning to defend against undisclosed attacks.

2.3. Social Internet of Things (SIoT)

SIoT is characterized as a developing paradigm of IoT where things are equipped for setting up social relationships with different objects. Jung *et al.,* [13] have proposed a prediction model that surmises the social relationship among objects by capturing the spatio-temporal attributes and assorted variety of the co-usage data. It fails to address how the model deals social connections strengthening and deterioration with time. Furthermore, large datasets from numerous domains could also be utilized. Tran *et al.,* [14] explained the traffic information sharing system utilizing the SIoT with fog computing. It describes about imparting a productive traffic data sharing and dissemination system by giving road and surrounding awareness, to limit the road accidents. The implementation of this architecture in the real world can be beneficial to the intelligent transportation system to a high degree. Lin *et al.,* [15] proposed a trust model that is tailored to the SIoT. It comprises of six essential components: trustor, trustee, goal, assessment of trustworthiness, decision and its subsequent action result, and the context. It does not directly address the social factors that sway the trust factor, so as to impact the consumer adoption intention decision and has focused on the specialized issues of SIoT usage but dismissed the SIoT users and their perceptions about the technology.

2.4. Social Internet of Vehicles (SIoV)

SIoV is a vehicular usecase of the Social IoT (SIoT), where vehicles are the key social components in the machine-to-machine vehicular social networks. Younis *et al.,* [16] have described employing the cyberphysical systems for improving the flow of traffic utilizing a dynamically changing traffic lights by gathering road conditions from sensors deployed on the road sides. The techniques are simple, quick and have low overhead to apply it on road traffic. However, it does not address cyber-physical systems for traffic security such as avoiding accidents. Atzori *et al.,* [17] explained the implementation of SIoV and portrays the attention on the cloud-based IoT platform to deal with the social activities of the vehicles. They characterize the relationships that can be built among the vehicles taking part in the SIoV. The experiments with the 802.11p protocol is hard, as there are relatively few relevant products in the market, most likely by the vague guidelines in the utilization of the applicable frequencies for vehicular communications. Silva *et al.,* [3] explored the broader SIoV systems with the V2V and V2I communications to enhance the traffic efficiency and road safety. In addition, they stress on the significance of ethical guidelines in planning and deploying of the SIoV frameworks. Though the performance is good, it is not intelligent enough to proficiently deal with the high-level intelligent network resources and smart vehicles in IoV systems. The works presented above utilize many diverse techniques for traffic management. They intend to solve the issues of detecting and avoiding congestion, managing vehicle routing decisions. But the consideration of accidents in the model, the purpose of social relationship establishment and the improvement of throughput parameters is not explained.

In our work, we emphasize about the social aspects of the relationships among the vehicles, commuters and RSUs. Various relationships can be applied to different kinds of vehicles to achieve the goal of having a better traffic flow that is free from congestion and accidents. Additionally, we consider the throughput parameters involving the flowing rate of vehicles and their non-conflicting movements at an intersection.

3. Motivation and Problem Statement

This section explains our motivation for traffic congestion management, it comprises of an overview on the background work and the problem statement.

3.1. Background Work

Chen *et al.,* [18] presented a throughput optimization framework - Dynamic Throughput Maximization Framework (D-TMF) that employs turning intentions and the positions of the lanes to increase the traffic flow. A four segment road intersection with four road movement types are considered. With the aid of, passing rate of the last vehicle in a stationary or moving queue, and scheduling the right type of movements for specific lanes in a road segment to design a dynamic traffic control system. The scheduling of the movements generate a binary phase matrix, that indicates the non-conflicting permitted movement types for the road segments of intersection. Further, a fairness provisioning algorithm is also formulated to avoid the phase matrix with higher aggregated passing rate to pass over the intersection repeatedly.

However, the existing system presents the idea of a vehicle waiting at a signal for a long time to get the priority to pass the intersection and they do not provide the quality-of-service to improve the whole user experience and to higher priority vehicles, like ambulances, fire trucks, police cars, *etc*. This results in an inappropriate traffic flow. This motivates us to propose a traffic congestion management through social features to improve traffic flow and enhance fairness utilizing relationship types. We add the trace of social parameters to estimate the flow count followed by designing the condition matrix which is independent of the lanes or movement types and left/right hand driven vehicles. We also propose a rational provision to improve the signal scheduling by giving accurate priorities incorporating the social attributes.

3.2. Problem Statement

The dynamic traffic signal management problem is defined as follows. At an intersection, each road segment has traffic flows consisting of right-only, go-straight, straight-right, left-diagonal, all through, and straight-left movement vehicles. Green signals are to be assigned to the movement of traffic at the intersection which does not result in any conflict or cause a congestion. The aim of this work is to determine the next non-conflicting flow and resolve the extent to which the traffic can be allowed to pass the intersection with green signal, and address the following.

1. Estimation of Flow Count: To improvise the traffic flow, by adding a trace of social parameters.
2. Dynamic design of condition matrix that is independent of the lanes or movement type and left/right-hand driven vehicles.
3. Maximizing the throughput with the allocation of green signal for a specific time to increase the traffic flow with the formation of social relationships among the vehicles, commuters and RSUs.

4. System Model

In this section, we explain the overall flow of our system architecture. With the help of dynamic control of the green signal to pass the vehicles and integrating the social features, an effective congestion management framework for the flow of traffic is illustrated. In this model, we have a six-road segment intersection that connects a crossing of three tracks at one junction; for instance, crossing of vertical, horizontal and diagonal tracks as shown in Fig. 1. To maximize the traffic flow passing an intersection, we adopt the flow count of the vehicles along with their social relationships and the dynamic design of condition matrix as explained in the following.
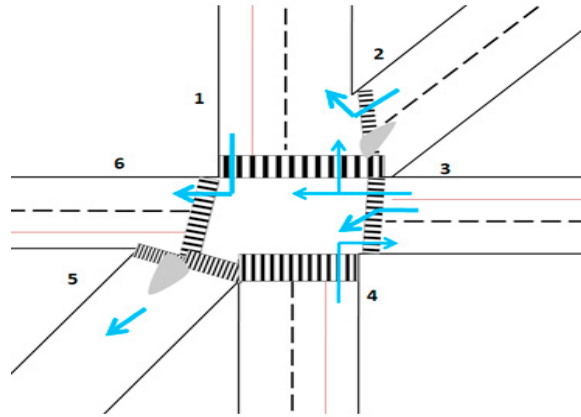
Fig. 1. The road intersection considered in our work.

4.1. Flow Count

The Flow Count describes the amount of traffic allowed in a lane to pass through the intersection. Consider the lane i on road segment j, the flow count for this lane at an Intersection I is obtained by the following equation.

$$c_{ij} = \frac{n}{\Delta t_{ij}} + c_p + \alpha w_{ij} \tag{1}$$

With n being the number of vehicles in the queue waiting to pass the intersection and Δt_{ij} is the anticipated time required for the last vehicle in the queue waiting to pass the intersection. Incorporating the aspects of social attributes, we can acquire the vehicles position, acceleration, their social needs *etc*, to achieve accuracy, where c_p is the vehicle flow count. The weighting factor is assigned to a range of relationships among the vehicles and RSUs, along with the scale is given by αw_{ij}. The relationships that provides more service is assigned a higher weighting factor and the relationships that obtains assistance from others to solve problems is assigned the next high weighting factor. The same follows with the rest of the other relationship types.

4.2. Condition Matrix

The Condition matrix schedules the non-conflicting way for the vehicles on the lanes to pass the intersection. For the vehicle movements on the roads, we are considering right-only, straight-right, go-straight, straight-left, all-through, and left diagonal movement types, as shown in Fig. 2 (a). Here we consider a binary condition matrix for the given movement types to represent non-conflicting movements among the vehicles passing the intersection. Irrespective of the number of lanes or the road segments a set of non-conflicting condition matrices, $M = \{M_1, M_2, ..., M_n\}$ that are applied to a traffic pattern are generated dynamically. In these binary matrices, qualified vehicles on the lanes to pass an intersection is assigned *1*, and not-qualified is assigned *0* as shown Fig. 2 (b).

4.3. Throughput Algorithm

With the aid of flow attribute we can estimate the maximum throughput, to allow the vehicles in a fair way. It is determined with the accurate calculation of the flow attribute for a lane and the vehicles chosen type of movement. Then flow count c_{ij} is computed and the aggregated flow count C_{ij} is determined for the road segments and the number of lanes. The value of the aggregated flow count of a road segment relies on a binary drift attribute D_{ij}^k of the road segment j of the i-th lane and for the k-th the movement type. If the movement type of the vehicle along with the social

(a) Types on Movements.

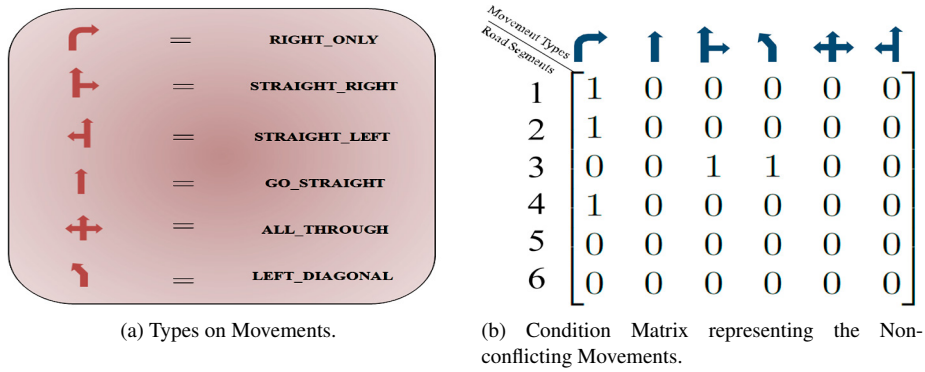(b) Condition Matrix representing the Non-conflicting Movements.

Fig. 2. Vehicle Movement Type and Condition Matrix

relationship is adaptable with the lane movement, then drift attribute is set dynamically to 1, if not, it is set to 0. For instance, if a vehicle desires to go in a left-diagonal direction in road segment 3 on lane 6, the straight-right direction is set to the other lane of road segment 3 given as $D_{6,3}^3 = 1$ and $D_{5,3}^4 = 1$, these are the non-conflicting movements for that road segment. Similarly, on road segment 6, the right most lane can be set to straight-right and left lane to straight-left simultaneously, setting the binary drift attribute to 1 for those lanes and 0 to others.

The aggregated flow count is estimated by the flow count c_{ij}, and the drift attribute D_{ij}^k of all the road segments. The aggregated flow count is incorporated with the social attributes to maximize the traffic flow and give a fair opportunity for all the vehicles, where they can communicate with each other. With the summation of flow count including the social attribute and the weighting factor of the entire road segment and multiplying with the drift of the vehicles, we get the aggregated flow count. To set the green sign duration for allowing the vehicles to pass the intersection in the next phase, we choose the condition matrix with the maximum aggregated flow count M_{max}. We do these computations dynamically to get the maximum value for allowing the vehicles in a lane, to prevent long waits, and to assign a green signal for non-conflicting movements. The steps for throughput maximization is outlined in Algorithm 1.

In SIoV, a vehicle which is a mobile node, comprises of the On-Board Unit (OBU) whose essential job is detecting and building the vehicular communication. Additionally, there exists a static node called a Road Side Unit (RSU) whereby it has its geographical location, storage device and at least two network interfaces, which constitutes the road side infrastructure. Based on the communication between the vehicles and with the RSUs the following social relationships are defined.

1. *Approach Object Relationship (AOR)* - AOR exists between vehicles, where they are present in the same physical geography intending to share the public information and messages.
2. *Group Object Relationship (GROR)* - GROR is formed where vehicles obtain updated information from a group of social friends travelling through the same routes about the conditions of traffic [17].
3. *Priority Object Relationship (PROR)* - When a higher priority vehicle, for instance, an ambulance, proceeds towards a vehicle, this vehicle establishes the PROR.
4. *Distant Object Relationship (DOR)* - The vehicles from the same producer come in contact with others to know if they have encountered and the technique used in resolving.


Algorithm 1: Throughput Algorithm

**Input** : Information of vehicles passing an Intersection
Output: Condition Matrix with the Maximum Aggregated Flow Count M_{max}

1 Determine the drift attribute according to the intention of the vehicle-turn D_{ij}^k.
2 Determine the flow count c_{ij} incorporating social attributes.
3 Determine the aggregated flow count C_{ij}.
4 Choose the condition matrix with the maximum aggregated flow count M_{max}.

5. *Visited Object Relationship (VOR)* - When a vehicle passes through or gets in contact with a premises or a building previously visited (from the historical data of the vehicle) it forms a VOR.

6. *Resource Object Relationship (ROR)* - A public transport vehicle e.g., a bus establishes a ROR with other buses, this relationship executes the resource request by co-ordinating the same resource configuration.

7. *Possession Object Relationship (PSOR)* - PSOR is formed between different objects, like smart phones, tablets, smart watches etc., of the single user and connects these computing devices to his/her vehicle establishing a relationship between these objects with the vehicle he possesses.

8. *Parking Object Relationship (PKOR)* - PKOR is established between the vehicles GPS receiver, smartphone navigator and a sensor service platform. This enables a vehicle and its driver to obtain available parking spaces from real-time collected data.

9. *Administrator Object Relationship (ADOR)* - The RSUs acts as the preserver of the OBU in case of any extremity and forms a relationship with OBU by apprising it with the needful information during the crisis for instance.

10. *Lane Object Relationship (LOR)* - If a vehicle wishes to change its lane from an arterial road to a service road for instance, it forms a LOR relationship with the vehicles around it, for them to assist it in changing the lane without causing any congestion or delay in the flow of traffic.
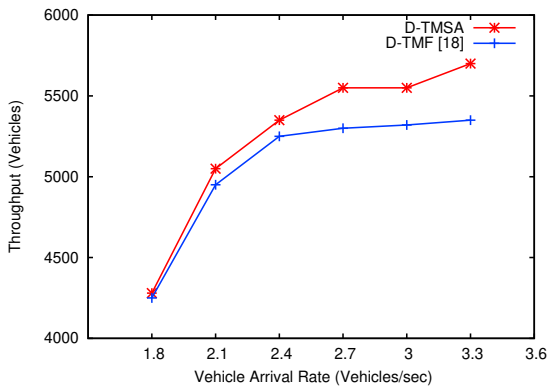
(a) Comparisons of Throughput under 75 percent straight-right, 15 percent right-only, and 10 percent left-diagonal turn cars.
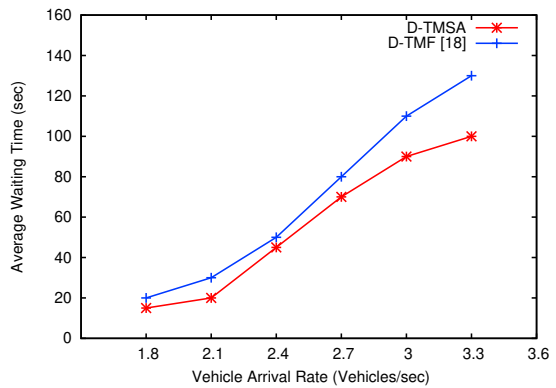
(b) Comparisons of Average Waiting Time under 75 percent straight-right, 15 percent right-only, and 10 percent left-diagonal turn cars.
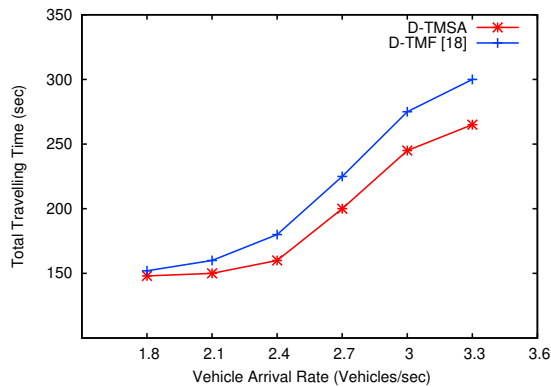
(c) Comparisons of Total Traveling Time under 75 percent straight-right, 15 percent right-only, and 10 percent left-diagonal turn cars.

Fig. 3. Performance of the Proposed D-TMSA Scheme in Terms of Throughput, Average Waiting Time and Total Traveling Time.

5. Performance Analysis

We simulate our framework through a traffic simulation software called Simulation of Urban Mobility (SUMO) [19], that is a persistent, microscopic and multi-modal traffic simulator. It produces various traffic demands consisting of vehicles moving across a given road network. We generate traffic demands with control traffic signs *via.* the Traffic Control Interface (TraCI) protocol. Six types of vehicles, car, bus, truck, police van, ambulance are assumed. An intersection consisting of six road segments is simulated, the vehicle movements here are right-only, straight-right, go-straight, straight-left, all-through and left diagonal. The TRaCI protocol is included in a python program to facilitate the overall movement of the traffic, and to interact with SUMO. Each simulation is carried out for 2000 seconds and five condition matrices are dynamically generated for the six road segments and movement types. we evaluate the performance of the D-TMSA scheme in terms of throughput, average waiting time and total traveling time.

Throughput. It is the total number of vehicles that passes the road network in each simulation time. Fig. 3 (a) illustrates the intersection throughput for different arrival rate of the vehicles under 75 percent straight-right, 15 percent right-only, and 10 percent left-diagonal turn cars, with the total number of vehicles passing the intersection in 2000 seconds. The simulation results show that the D-TMSA achieves higher throughput compare to the D-TMF. The intersection throughput increases gradually as the vehicle arrival rate increases.

Total traveling time. It is the total time from entering to leaving the intersection of a vehicle. Fig. 3 (b) shows comparisons of the total traveling time under 75 percent straight-right, 15 percent right-only, and 10 percent left-diagonal turn cars. We can observe that the total traveling time of the proposed scheme is further reduced through the use of various relationship types among vehicles, commuters and RSUs.

Average waiting time. It is the total stopover time at the intersection per vehicle. The average waiting time of the vehicles at the intersection is reduced by establishing various social relationship types as shown in Fig. 3 (c).

Based on the traffic demand set in the program we have simulated our framework with the throughput maximization concept to control the traffic signals and increase the flow count.

6. Conclusions

In this paper, we propose a SIoV based traffic congestion management to control the congestion and improve the flow of traffic with the aid of social, behavioral and preference based relationships. These relationships are established between the vehicles, commuters and the RSUs. We design a road intersection with each road having several lanes with different vehicle movement type. While the vehicles travel along the road they build social relationships each other based on their needs. We propose a way of maximizing the flow of non-conflicting traffic by structuring it dynamically. The simulation results show that D-TMSA under different vehicle arrival rates achieves higher throughput, scale down the average waiting time and reduces the total traveling time of vehicles on the road network. The throughput maximization with the fairness scheduling can be further investigated to provide a even better result for the traffic allowance in regard to the priority of vehicles.

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