ORIGINAL ARTICLE

Traffic Management system and Traffic Light Control in Smart City to Reduce Traffic Congestion

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Abstract: Traffic congestion becomes a serious problem when there are many vehicles on the roadways. The queue of vehicles waiting to be treated at intersections increases significantly as road traffic increases, and traditional traffic lights are unable to handle it. The synchronization mechanism used by traditional circulation lighting systems changes light signals after a certain interval. This method is used when the roads are nearly empty. An intelligent traffic light system detects the presence, estimates the level of traffic, and reacts appropriately. Intelligent traffic systems are designed to prevent cars from impatiently waiting at traffic lights to change their signals when there are free roads. In this study, we develop a simulator in which a traffic grille made of traffic lights is constructed at intersections resembling those in large cities, and the flow of vehicles through the grid is optimized by developing algorithms for how traffic lights change their state. To maximize vehicle movement over the grid, scheduling algorithms are being developed to control how road traffic changes. Because of the encouraging response to our models, we were able to achieve good results that reduced the waiting time by 30% compared to the default model.

Keywords: Smart city; Scheduling; Road traffic; Traffic lights; Traffic Congestion; Multi Agent system.

Introduction

Numerous aspects of our lives have become more appealing because of the use of technology, but the transportation industry has taken a long time to recognize its ability to become rat trapped. These advancements are now unavoidable. The road environment is becoming more complex because of the increased complexity brought on by the consequences of the rapid growth in vehicle numbers as well as smarter vehicles.

Smart cities are employed in various aspects of society, including hospitals, offices, industries, and parking lots. [1]. The rise in traffic and the population both contribute significantly to several issues. Public health and the environment are affected. They are brought on by the release of greenhouse gases, and when traffic congestion increases, vehicles release pollutants. The economic costs associated with fuel use and times wasted in traffic congestion are not ignored. Declining traffic conditions also contribute to accidents and disasters.

This context has motivated the IT community to take an interest in smart cities. A smart city is a city using information and communication technologies to improve the quality of urban services or reduce costs. A city combines an efficient, low-emission, sprawling and accessible public transport network with efficient communications, "smart" parking, synchronized, efficient and energy-efficient streetlights, and an entire traffic management system. This tends to reduce congestion. The main objective of our study focuses on urban crossroads and ways to limit the waste of time and resources.

The big problem is that the delays caused by congestion have a significant impact on the user's quality of life. Indeed, drivers who are stuck in traffic jams are often affected by stress, noise, etc., and have an increased risk of accidents. This phenomenon is widely regarded as an indirect source of health problems and has a direct impact on the increase in vitality consumption.

Traffic lights are already in place to manage the flow of traffic, but they are becoming increasingly ineffective due to their design. Preset time varies between shades of green, orange, and red, regardless of current conditions, leading to increased waiting times, additional fuel consumption, and air pollution, among other things. Additionally, there is a lack of improved driver knowledge about the state of the roads. To better meet the needs of road management, it is necessary to establish more efficient, economical, and sustainable transport systems through the improvement of traffic signals. The key challenge is controlling the traffic light timing to find the fastest route between two places in order to simultaneously reduce travel time and minimize congestion. The proposed traffic management system utilizes traffic light control to avoid congestion. In this study, we introduce the agent-based traffic management system, a multi-agent traffic signal timing system that works cooperatively to reduce congestion. In the suggested system, agents that can directly link to one another are added to intersection controllers. By carefully taking into account the feedback from each agent who is impacted by a change, the agents cooperatively adjust signal timings.

The researchers focused their efforts on enhancing traffic flow in response to these worries and issues with unforeseen road traffic, and they presented many algorithms to reduce congestion and maximize the utilization of current road infrastructure.

The installation of sensors that inform users of the current traffic conditions was the subject of research in [2]. A city with traffic sensors improves traffic efficiency and reduces pollution in the city. The city's orientation graph G = (S, E, v), whose road nodes are the vertices S and the roads are arcs A, is used to model the city.

The model is based on a multi-agent architecture, with the agents being local resolution systems that represent sensors that were installed on the pavements using the SUMO simulator. The execution time is up to ten times faster than the Round Robin Algorithm in this study, and the task distribution is more random. Similar to the task scheduler we have already seen, the employment of ACO is highly promising and will allow for the achievement of excellent results in the problem of road traffic planning. The waiting issue will finally be reduced and brought under control.

In study [3], the authors performed a comparative analysis of 7 different regression models to find out which model gave the best accuracy, in which Multilayer Perceptron provided the best outcome. The result of the model is amplified using the amplification ensemble method and passed to the next regression model, which shows that the proposed framework gives better results than the 7 regression models above. The experimental results show the effectiveness of the proposed framework, which reduces the error rate by 2.47%.

The Adaptive Traffic Control System (ATCS)[4] is a traffic management approach that modifies or adapts the timing of traffic signals based on the actual demand for traffic and is accomplished utilizing a control system that incorporates both hardware and software. The proposed approach is to split the problem into two sub-problems, the first of which is to calculate traffic volume using classifiers under the Viola-Jones Object Detection System. With the use of OpenCV libraries in a C/C++ environment, an estimate of real-time traffic volume was obtained. Unlike other libraries, OpenCV was selected for its time-efficient and reliable performance in real-time projects. The second sub-issue included the development of an algorithm control system to overcome traffic jams. The control algorithm is responsible for controlling traffic at the intersection when it receives data. The model of the camera-based traffic monitoring and processing system presented in this research has a shorter cycle time and special facilities for emergency vehicles.

This study [5] suggests a Q-learning-based TSC system that maximizes the number of vehicles passing through an intersection and balances traffic signals between routes. The main benefit of this study is that it has a QL structure that may be used at various crossings. The proposed technique applies the different types of waiting for line lengths to calculate rewards after four different crossings of the performance were studied. The suggested method performed well in terms of the standard deviation of queue lengths, as well as decreased waiting times and queue lengths.

The study [6] proposed three synchronization protocols to improve traffic light control at signalized intersections. When the negotiating vehicles arrive, the ICANP (intelligent context-aware negotiation protocol) first stops the green timer for the regular vehicle phases so that the negotiating vehicles can pass quickly through the indicated intersection. Significant improvements have been made by the ICANP in terms of vehicle negotiation wait times. It increased total wait times at each fire by 65% compared to the circulator and performs 42% better than ITLC (intelligent traffic light controlling) [11]. Here the authors also introduce the Negotiation Protocol Based on Reputation (NPBR). This method tries to reduce the negative effects of unauthorized vehicle entry congestion. It takes advantage of the drivers' reputations to estimate the number of dishonest vehicles. In comparison to ITLC and ICANP, NPBR reduced vehicle negotiating wait times by

64% and 45%, respectively. Third, this study provides an intelligent context prioritizing process (ICAPP). The most prestigious priority vehicles receive final consideration. According to ICAPP, they can pass through the crossing without having to negotiate. The wait time for priority cars was reduced by half using ICAPP as compared to CATLS (a context-aware traffic light scheduling) [13].

The authors of this study [7] suggested a dynamic congestion control with throughput maximization system based on social aspects using relationships based on social, behavioral, and preference data (D-TMSA). The following is presented in [7] the paper's annotations: 1. A dynamic congestion control system through the use of various types of relationships increases the overtaking rate and allows traffic flow, 2. Maximize non-conflicting traffic flow by dynamically structuring it. Maximize flow to control traffic lights and increase the number of flows. According to the simulation results, the D-TMSA performs better than the previous work by achieving high throughput, reducing total travel time, and decreasing the average waiting time to improve traffic flow based on their social features with each other.

To help traffic management authorities effectively handle traffic congestion in cities, authors [8] proposed the Adaptive Traffic Light Control System (ATLCS). The main goal of ATLCS is to synchronize a number of traffic lights that govern adjacent junctions by delaying the moments when each one turns green in a certain direction. In order to minimize the number of occurrences of the "stop and go" phenomenon, this delay is dynamically updated based on the number of vehicles waiting at each junction. This allows vehicles leaving the city center to travel a far distance without stopping, which in turn minimizes their travel time. When compared to non-synchronized fixed time Traffic Light Control Systems, the average travel time of cars traveling in the synchronized direction has been significantly reduced (by up to 39%) according to the performance evaluation of ATLCS. Additionally, a 17% improvement was made overall across the entire simulated road network.

This study [9] suggested a queue length standard deviation and throughput as the main parameters for a Q-learning-based traffic signal control system. The proposed technique shows good performance in terms of the standard deviation of queue lengths coupled with the decreased waiting period and queue length compared to earlier research utilizing Q learning. It is assumed that the traffic signal management system recognized the direction of the flow of traffic and distributed the signals appropriately. This study looked at traffic signal control that can be applied to different intersection types. The suggested research includes a flexible design that can be altered to accommodate changes in the intersection's original structure. The suggested method performed well in terms of the standard deviation of queue lengths as well as decreased queue lengths and waiting times.

In this paper [10], a smart traffic signal control system (STSC) is proposed and built. It covers a number of smart city transportation applications, including message broadcasting, adaptive traffic signal control (ATSC) [14], support for Eco driving, and public transport signal priority. The core of the proposed STSC system is the roadside unit (RSU) controller. A new traffic signal scheme is specially designed for the EVSP scenario, it can inform all the drivers near the intersection regarding which direction the emergency vehicle (EV) is approaching, smoothing the traffic flow, and enhancing the safety without adding hardware costs.

After analyzing previous works related to the problem of traffic congestion (see Table 1), the greatest throughput and the smallest average waiting rate are selected as objectives for a better control of traffic signals under congested conditions. The most of previous research decreased the average delay per vehicle or decreased the length of the queue. Additionally, we observed that the majority of earlier researchers used the SUMO simulator to implement their ideas; nevertheless, this simulator has a number of flaws. These limitations focus on scalability and fault tolerance issues [2], and the suggested scheduling algorithms are Java-based. As a result, we decided to carry out this study using a Java simulator, which is suitable for our conditions and takes into account all of the constraints of the suggested algorithms.

Methodology

The characteristics that follow are expected to be present in the ideal traffic management strategy: it should be general enough to be used at various intersections, it should be adaptive and able to optimize control settings, it should be aware of real-time traffic conditions and predict traffic conditions, and it should have the learning capacity to improve control strategy. According to the available literature, there is currently no control system that can integrate all of the above competencies and satisfy the outlined features.

The multi-agent system properties that support their use in this work are provided in this section. The MAS approach is more of a management methodology than a traditional controller of green time is, with agents working together and competing to find the optimal solution for their own objectives while taking into account the present traffic demand and potential future traffic regulations.

Table 1. Comparison of related works.

Paper / year	***Contribution***	***Advantages***	***Future works***	***software used***
[2] 2019	1. Installing sensors that give customers real-time information about traffic situations. 2. Improves transportation efficiency and reduces pollution. 3. The model is based on a multi-agent architecture with local resolution systems serving as the agents, who represent the sensors mounted on the roads.	1. Optimize task distribution and gain If randomization is used, the execution time can be up to 10 times compared to the Round Robin Algorithm. 2. using ACO is very promising and will produce excellent results for the problem of road traffic planning 3. Packing will be reduced and under control.	-1. A traffic simulator should be developed to test the suggested algorithm. -2. Comparing the outcomes with other approaches - 3. minimizing the amount of time spent in traffic jams	SUMO simulator[12]
[3] 2021	1. A comparison analysis of seven different regression models was conducted to determine which model provides greater accuracy.	The experimental findings demonstrate the efficacy of the suggested framework, which lowers the error rate by 2.47%.	Future research should incorporate expanded experimental dimensions.	python 3.7.
[4] 2021	two sub-problems : the first of which is to calculate traffic volume using classifiers under the Viola-Jones Object Detection System. The second sub-issue included the development of an algorithm control system to overcome traffic jams.	-It takes 105 seconds to move the traffic for 100 vehicles, which is substantially less time than the conventional methods. -eliminate congestion more quickly. -Low fuel consumption is also a result of the ATCS system's contribution to the reduction of noise and air pollution.	-not found	Using OpenCV libraries in the C/C++ environment,
[5] 2020	-maximize the number of vehicles crossing an intersection and balances the signals between roads by using Q-learning . -The proposed system has a flexible structure that can be modified to suit the changes in the original structure of The Intersection.	This study's key benefit is that it has a QL structure that can be used to analyze a variety of intersections. The performance at four different n-way crossings was examined. For calculating rewards, the suggested algorithm uses the standard deviation of queue lengths.	-Sharing information between intersections. -The system must communicate with nearby intersections in order to govern the intersection during the next phase.	SUMO simulator
[6] 2019	three synchronization protocols are suggested: 1. ICANP stops the green time allowed at the phases of regular vehicles so that they can pass quickly at a signalized intersection. 2- a negotiation protocol based on reputation, which minimises the congestion effect from incoming dishonest drivers . 3- ICAPP takes into consideration the vehicles with the best reputations as priorities. They may cross the intersection without negotiation according to the ICAPP.	1. ICANP is 42% better than IT LC and reduces the overall waiting time at each traffic light by 65% compared to the circular. 2. NPBR reduces waiting times for negotiating vehicles by 45% and 64%, compared to ICANP and ITLC respectively. 3. When compared to CATLS, ICAPP decreases priority vehicle wait times by 32%. 4. In comparison to the circular protocol, the suggested protocols significantly improves the pollution indicator CO2.	- investigate further hybrid meta-heuristics and optimization methods to address the congestion issue.-using, PSO (Particle Swarm Optimization) and NSGA (Non-dominated Sorting Genetic Algorithm) - Check the accuracy of L2LCR messages sent between traffic signals at nearby and distant intersections.	OpenStreet Map (OSM) Java jdk8u45

[7] 2020	1. Increase vehicle passing rates and promotes efficient traffic flow by utilizing different relationship types. 2. Maximize non-conflicting traffic flow by dynamically structuring it. 3. Maximize flow to control traffic lights and increase the number of flows.	Use of various forms of relationships between vehicles and passengers reduces the suggested plan's total travel time significantly.	-not found	SUMO simulator[12] python
[8] 2020	-Reducing the number of "stop and go" situations that can happen as a vehicle travels along arterial highways that connect major centers. -demonstrating the effectiveness of ATLCS	- The precise calculation of the number of cars on the road. -the average travel time of cars driving in the synchronized direction has been decreased (by up to 39%). Additionally, a 17% improvement was made overall across the simulated road network.	test the proposed algorithm on real world scenarios	SUMO simulator [12] python
[9] 2020	-maximize the number of vehicles crossing an intersection and balances the signals between roads by using Q-learning (QL)	-good performance in terms of standard deviation of queue lengths along with shorter queue length and waiting period	-cooperation among intersections adjacent to each other. -control the traffic signal more efficiently by sharing information between intersections than by using only local information.	SUMO simulator[12]
[10] 2020	-a smart traffic signal control (STSC) system is designed and implemented -it can inform all the drivers near the intersection regarding which direction the emergency vehicle (EV) is approaching, smoothing the traffic flow, and enhancing the safety without adding hardware costs	-support various smart city ITS applications including EVSP, TSP, ecodriving, ATSC, pre-time signal control, and R2V message broadcasting	- real-time traffic information fusion for ATSC by integrating multiple data sources - Kernel optimization in middleware modules such as message handling, state transition, and parallel processing are planned to be implemented.	RSU controller, OBU, signal controller, and cloud center.

The contributions of the proposed technique

1. A multi-agent architecture was used to design a traffic signal control approach for traffic intersections, where each signalized intersection builds on an independent multi-agent system. Agents negotiate and select the appropriate time for implementation. No agent has more control than other does. Where agents work together and compete to find the best solution for their individual objectives, taking into account the recurring traffic demand and potential traffic laws that may be applicable.
2. The capability to modify the traffic management protocol with simply a new scheme added to the current schemes, the suggested traffic control has the capability to generate all possible traffic signal plan designs.
3. The proposed approach aims to reduce delay to the minimum. Such a strategy can reduce the time that cars must wait to move, improve intersection traffic flow, and lower exhaust emissions. In a summary, this strategy lowers gas emissions and fuel consumption while simultaneously increasing the effectiveness of the road transportation system.

The proposed simulator includes two subsystems:

1. The traffic network is created and managed by the environment system;
2. Zone managers and intersection controllers are both created and managed by the multi-agent system. The various agent types communicate by generating and sending individual messages to each other. This is known as message passing.

Environment system

A highway can be categorized as an inhospitable, nondeterministic, non-episodic, dynamic, and continuous environment. It is unavailable because highway management agents can only get data from human operators and data measured by detectors, making it inaccessible. This data can never be both accurate and complete. The same agent's activities won't always have the same effects because the highway simulates the real physical environment, which must also be taken into account for upcoming tasks. We shall therefore regard the highway as a non-deterministic, non-episodic environment. It is also dynamic since drivers' actions and, consequently, the general flow of traffic on the highway are somewhat influenced by agents. Lastly, a highway has a certain continuous nature, and the information from the highway detectors is continuously acquired.

The movement of cars through the grid is improved by creating a multi-agent system for how traffic lights change their state, which uses a grid of streets with traffic lights at intersections resembling those in large cities.

Multi-Agents system

It is important to address the question of why use the Multi-Agent System Paradigm before describing the multi-agent system's architecture.

The three characteristics that make MAS applications in the field of traffic management the most appealing are: Autonomy, Collaboration, and Reactivity.

To address the issue scalability, we suggest three-level architecture (see figure.2).

At level 0, we find the Grid Agent, to which cars register when they enter grid. This last one is in charge of registering cars, sending decisions to controller agents, and startup all other agents.

At level 1, the controller agent is connected to a road (avenue or street), and it is in charge of maintaining traffic-related information for each of its intersection, sending decisions to its related intersection agents, and receive information from each car agent and identify which intersection agent this car belong.

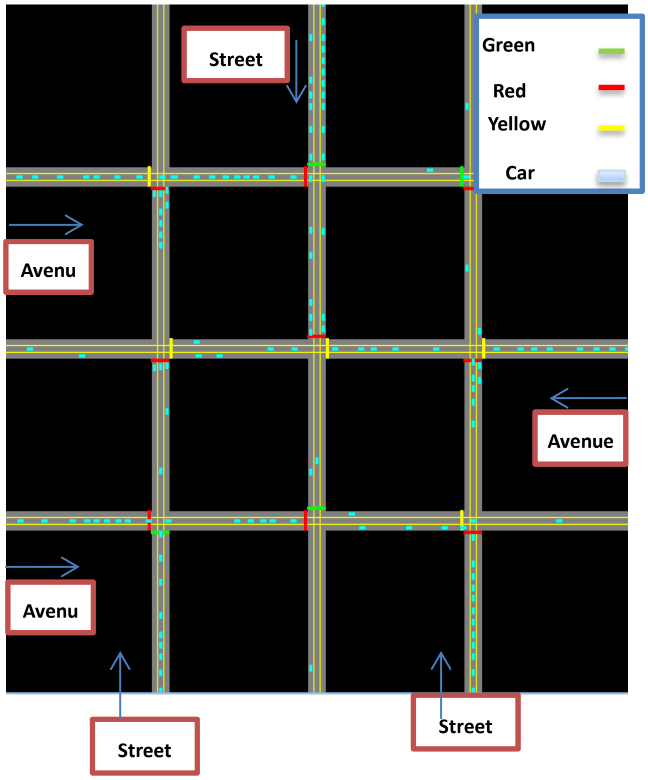

Figure 1. Grid of streets and avenue

Figure 1 show that there are two traffic lights at each intersection. There are two type of road (street or avenue), each road has multiple lanes and two directions (Forward Lane and Turning Lane).

At level 2, we find the car agents, intersection agents, and traffic light agents; it is necessary to have an intersection agent on each intersection. Each intersection agent at this level is accountable for maintaining their traffic information, sending that information to their associated controller agent, working with controller agent and traffic light agents to solve the congestion problem.

In the proposed multi agents system, the intersection is composed of two types of agents: intersection agents and traffic light agents. At an intersection, there is one intersection agent and two traffic light agents.

The intersection agent is in charge of changing the timing of traffic lights and making sure that these modifications does not violate any fundamental traffic laws. In addition, the intersection agent communicates with controller agent and neighboring intersection agents in solving congestion.

However, traffic light agents indicate only a small number of authorized car movements at the intersection. One or more movements are delegated to each traffic light agent for management. The traffic light operators compete with one another for control over changes to the timing of the lights.

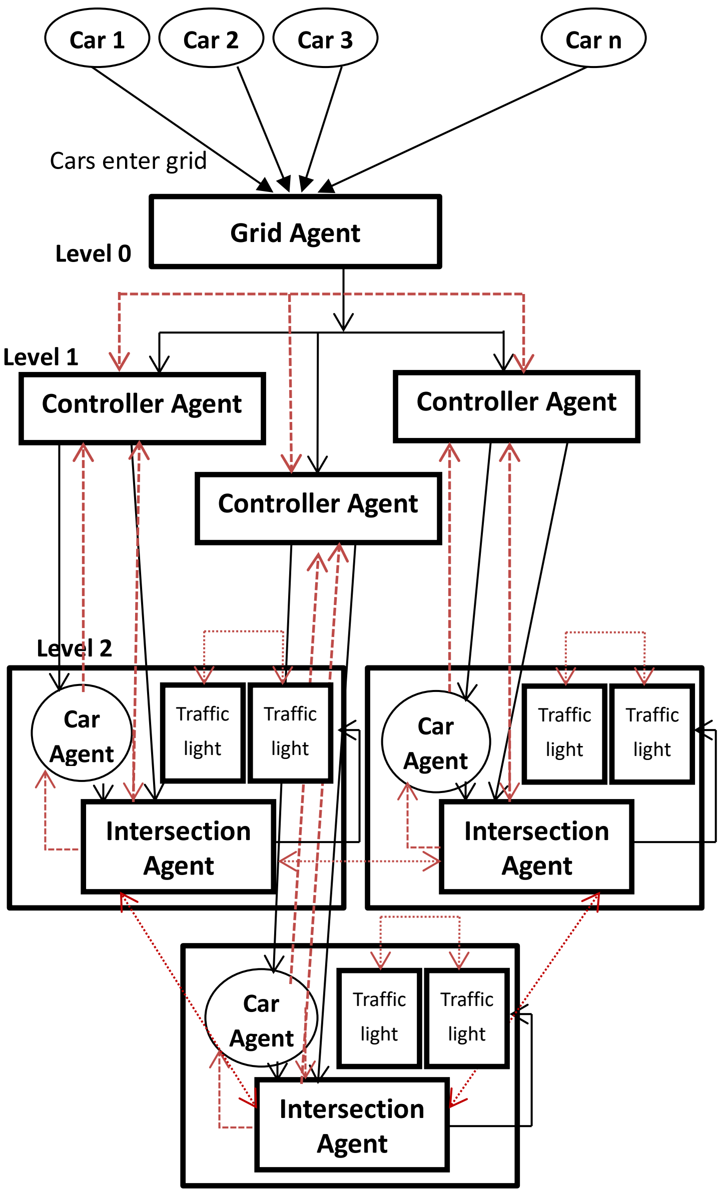

Figure 2. Multi agent system's architecture

To adjust light timings in real time, traffic light agents and intersection agent collaborate at the intersection level. The changes are made to increase the intersection's effectiveness and maintain its safety.

Car agent incorporates both the characteristics of a car and the complicated human driving behavior. Car agent communicates with other agents to access the traffic network information. During travel time, car agent sends its position (x, y position in grid), car length and width, speed and number of turns every second to controller agent. Controller agent will identify to which intersection agent this car belong. The intersection agent estimates the traffic factor, also lane weight for each lane (it estimates expected Straight Cars and expected Turning Cars). If traffic factor of lane surpass threshold, intersection agent will send message to all car agents in this lane. The car agents will take a decision to change its direction (forward or turning) or wait in same lane. Also intersection agent will communicate with the previous intersection agent to stop sending cars to it (switch to red light) and ask the after intersection agent to open green light.

Intersection agent will send decision every second to traffic light agent. Traffic light agent will computes green time and cycle time using traffic factor. If traffic factor exceeds threshold traffic light agent will communicate with other traffic light agent in same intersection asking it to switch to red, also traffic light agent can communicate with another traffic light agent to increase green time to solve the problem of congestion.

Results and Discussion

The simulations 'important objective was to show that agent-based control has the ability to replace and potentially outperform the traditional centralized strategy.

Experimental environment

To evaluate the effectiveness of the proposed scheduling scheme, we set up an experimental environment using a simulator, which is a grid that forms a set of roads and crossroads that we represented in terms of street and avenue.

Everything we described earlier, including both the number and size of cars, the number of lines and intersections, and even the grid's dimensions, may be adjusted using the configuration file.

JADE (Java Agent Development Framework) was established for the implementation of agents. Using the Jade agent platform, agents in the proposed infrastructure can communicate in a grid context.

The proposed framework comprised agents: Grid Agent, Car Agent, Controller Agent, Intersection Agent , and Traffic light Agent.

The Grid Agent creates instances of Car Agent, Controller Agent, Intersection Agent, and Traffic light Agent in accordance with the configuration file to initialize the simulation.

Grid Agent reads the configuration file containing information about the Cars and roads, and dynamically creates the cars instances over time.

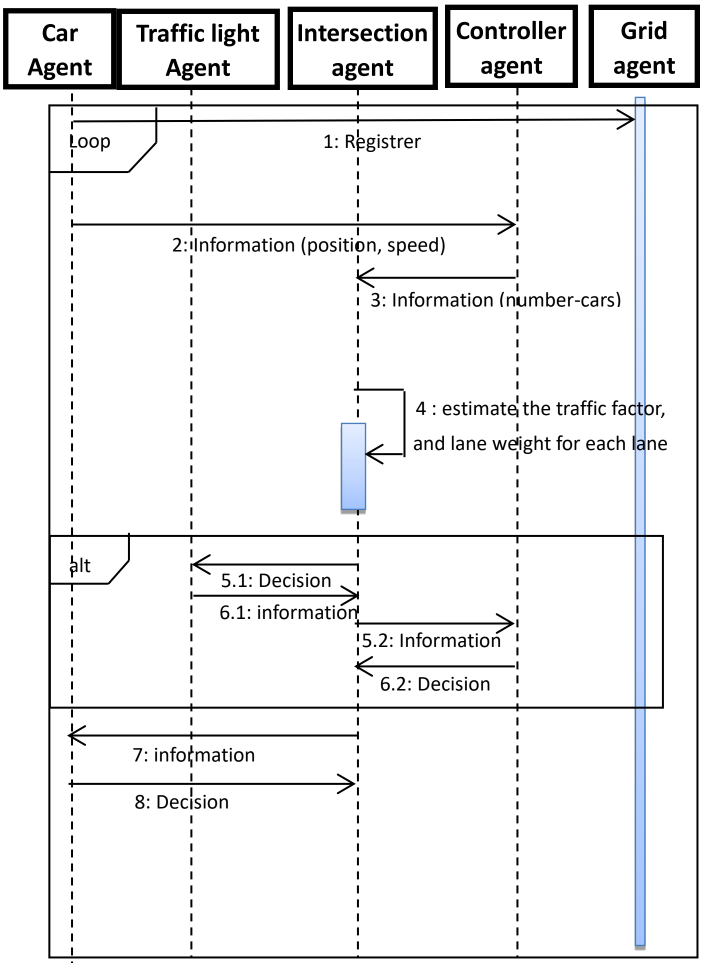

Figure 3. The UML sequence diagram in the traffic management process

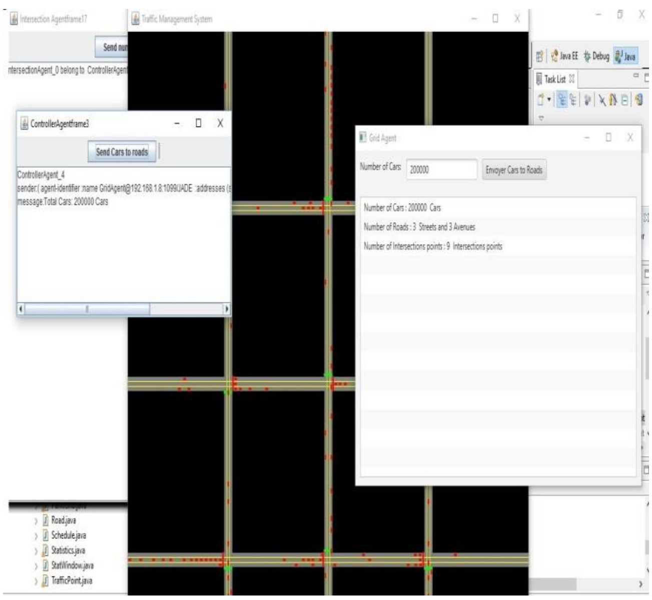

Figure 4. Proposed system interface

Simulation parameters

To test the feasibility and performance of the algorithms, we tested them in the simulator by using the following parameters:

Grid settings:
Number of streets and avenues
Maximum and minimum block side length
Parameters of cars:
Unique ID
X, Y position in the grid
Entrance direction
Exit direction
Number of turns
Maximum speed of the car
Acceleration of the car
Length and width of the car in pixels
Clearance distance for both sides of the car
Parameter of streets:
Road type //S=street, A=avenue
Road direction // traffic source direction
Entry point
Exit point
Number of forward Lanes
Number of tuning lanes
Traffic Point Parameter:
Maximum red and green time in seconds
Max red time could be max green time + Yellow Time in seconds.

Metrics used

We are focused on the following metrics:

1. Total waiting time of all cars: This is the total waiting time at the intersection by all cars.
2. Total moving time of all cars in the system: This is the total time between entering and exiting the intersection of all cars.
3. Average distance traveled by all cars in the line: the length of the space needed to get from one car to its destination.

Experimentations

We performed some experiments to evaluate the efficiency and performance of the proposed algorithm.

Experimentation 1:

In the first experiment, we focused on the total waiting time of all cars (in seconds) according to different numbers of cars.

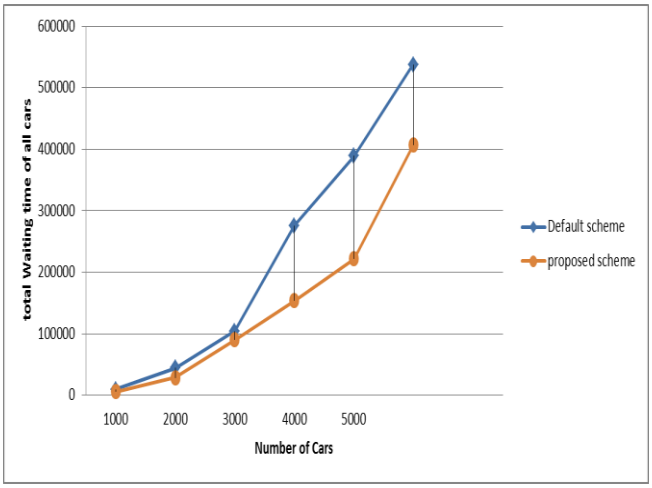

Figure 5. Total waiting time of all cars (in seconds)

Experimentation 2:

In the second experiment, we focused on Total moving time of all cars in the system. We have assumed that the number of cars vary from 1000 up to 6000

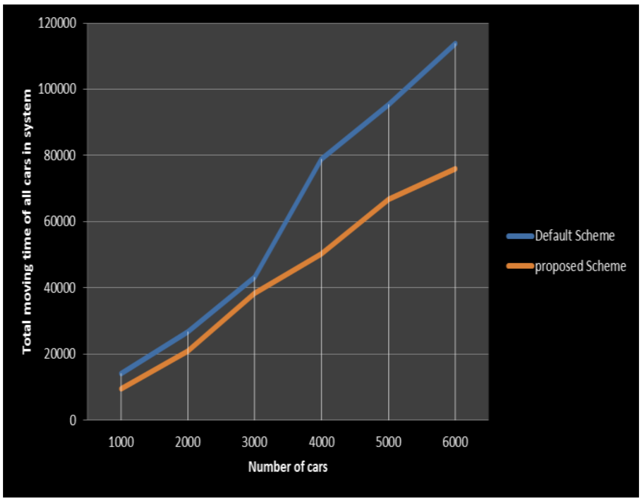

Figure 6. Total moving time of all cars in the system

Experimentation 3:

In the third experiment, we focused on the shortest distance traveled by all the cars on the grid. We assumed that the number of cars vary from 1000 up to 6000.

Conclusion

One of the many domains of a Smart City where there has been significant research is the traffic management system. It is a field of study that provides solutions to numerous current traffic management issues in smart cities.

The proposed model states that the number and density of cars traversing the main roads leading to the intersections determines when the traffic lights should turn green and red.

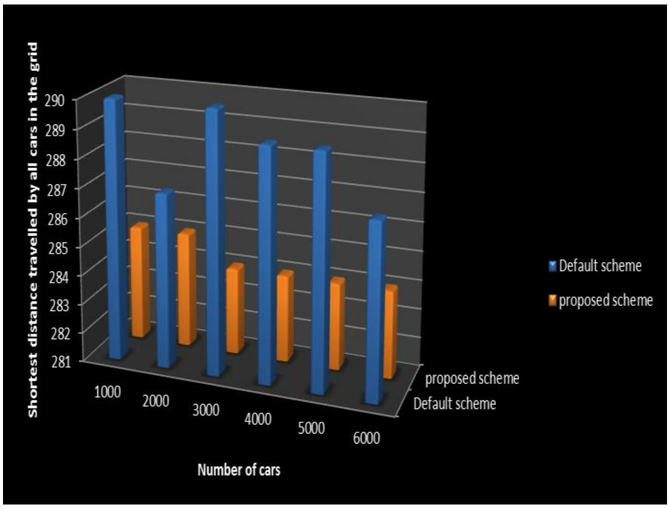

Figure 7. The shortest distance traveled by all the cars on the grid

This paper proposed a cooperative framework based solution for the Traffic Management and Traffic Light Control problem, utilizing multiple agents in a nine intersection environment for traditional and sustainability metric reduction purposes.

To solve the scalability problem, we suggest a three-level architecture. We find the Grid Agent at level 0. The controller agent is connected to an avenue or street at level 1 . Level 2 is where the traffic light, intersection, and car agents are located; one intersection agent is required at each intersection. At an intersection, there is a single intersection agent and two traffic light agents.

The suggested solution incorporates a few indications and models to enhance the network's overall traffic flow and decrease the average vehicle waiting time (by 30.40%).

The suggested technique eliminates the wait time for import ant patients and medications as well as emergency care for accident victims.

Different priority levels for various situations and scenarios can be taken into consideration for the future. Furthermore, we intend to use several intersection models, take into account different road conditions, and expand our algorithm and simulation environment to handle multiple intersections.

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