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Final Report

Self - Organized Transport System

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16. Abstract

This report presents the findings of the simulation model for a self-organized transport system where traffic lights communicate with neighboring traffic lights and make decisions locally to adapt to traffic conditions in real time. The model is inspired by the behavior of social insects which exhibit sophisticated collective behavior despite having limited individual abilities. The initial results show an improvement in average vehicle delay for the self-organized traffic system compared to some of the other basic traffic control schemes.

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Final Report: Self-Organized Transport System

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Abstract

This report presents the findings of the simulation model for a self-organized transport system where traffic lights communicate with neighboring traffic lights and make decisions locally to adapt to traffic conditions in real-time. The model is inspired by the behavior of social insects which exhibit sophisticated collective behavior despite having limited individual abilities. The initial results show an improvement in average vehicle delay for the self-organized traffic system compared to some of the other basic traffic control schemes.

Introduction

The primary objective of this research was to examine the concept of traffic light self-organization for reducing average vehicle delay and driver frustration. The concept of self-organization was inspired by the behavior of social insects such as ants and bees which are able to collectively exhibit remarkably sophisticated behavior despite having a very limited individual ability. Each insect has a limited behavior repertoire and interacts locally with other insects such that local interactions lead to global synchronization of behavior. Such systems where independent intelligent entities interact locally and exhibit sophisticated emergent behavior are called complex systems and their behavior is called self-organization. Similarly, in a self-organized traffic system individual traffic lights interact with neighboring signals to get information on timing pattern and traffic flow in order to adapt their own behavior.

Traffic signal synchronization is a complex multivariate optimization problem with variables including: road network topology, density of intersections, probability of hitting red lights, distance, speed, and traffic density of other cars (especially for left and right turns). It has a clearly defined objective function, i.e., minimizing the average vehicle delay. The design variables are clear as well, i.e., to define the green splits, cycle lengths, and offsets.

The problem is that with so many variations possible it is hard to model all the variables. Variation in the number and speed of vehicles are quite large – making it impossible to account for all combinations during optimization. This is compounded with other input such as time of the year and environmental conditions. While these systems can be adapted to respond to recurring traffic congestion, they are unable to accommodate irregular congestion and other variable conditions such as the weather, special events, and accidents. Even for recurring conditions, the performance of these types of systems is not optimal, since it is not based on real-time traffic conditions.

Traditionally traffic lights have been controlled individually using fixed-time systems that utilize either simple manual strategies or optimization packages to determine green splits, cycle lengths, and offsets using historical data. A step up in complexity from fixed-time systems is actuated light signals that react to the presence of vehicles at an intersection using detectors at minor roadways. While, they work well for peak-traffic conditions, they can cause problems for management of non-peak traffic such as when an entire lane of fast-moving traffic comes to a halt at a red light that was triggered a second earlier by a single car arriving on an intersecting road. In another case, a vehicle from a crossroad has to actuate a signal and wait for it to turn green when no vehicle is in sight for miles on the main artery.

There has been work on synchronization of multiple traffic lights where synchronization is usually done in one direction based on traffic volume often leading to unneeded traffic delay in the other direction. Several dynamic control systems have been proposed for traffic control based on traffic flows across multiple light signals; however, most of these are controlled at, and communicate with, a central location. Issues associated with such central control, include: scalability, resilience, and latency. As the number of traffic lights increases, the number of variables to optimize increase and performance becomes increasingly poor. The delays in acquiring, processing, and relaying information across multiple traffic signals also become worse as the number of signals increase. In addition, centrally controlled signals are not designed to deal with exceptions; traffic anomalies result in significant traffic disruption.

From past research, we can see that, in general, the more information a signal controller uses the better performance it can achieve. However, the complexity of algorithms for designing signal timing plans correspondingly grows as more information is being utilized. Another factor that complicates the problem is the number of signalized intersections considered. In the general case, with non-periodic signal timing plans allowed, the size of the problem grows exponentially as the number of considered signals increases. Therefore, in practice, the tradeoff between the accuracy of the algorithm, the amount of traffic-related information used, and the size of the network remains an issue. The self-organized transport system model inherently addresses these issues since the interactions are local and decision making is done at individual traffic signals.

Simulation Model

As a part of this effort a simulation model was developed to perform initial experiments on the efficacy of the aforementioned algorithm. We have used Mathematica for the model. This model can simulate arbitrary road networks and traffic characteristics at the individual vehicle level that meets given statistical criteria such as a mean density, source and destination locations, routes, and vehicle velocities.

1. Use a graph library and create an arbitrary network of roads. Each node of the graph is an intersection and each link is a roadway connecting two intersections.
2. Each link can be unidirectional or bidirectional (A link can be defined as a roadway which may consist of one or two arteries). The direction of flow of each artery will need to be defined.
3. The length of the links is arbitrary and the number of connections at any node is also arbitrary. In most cases though, we expect a four-way intersection.
4. Each link has a speed limit associated with it.
5. The state of each vehicle is defined by its position which will be identified by the relative distance from the starting node of the roadway.
6. Vehicles are generated at random positions within each artery and are also absorbed randomly at different positions in the artery.
7. The rate of absorption and generation of vehicles can be controlled in the model (initially we will start with the same rate for both). We will also have to introduce a congestion factor in the model that will not only impact speed but also the rate of generation of new vehicles.
8. For each connection at a node with n connections there should be n(n-1) queues that represents all the cars waiting at the intersection from each artery. Since cars from each artery can go in n-1 directions (we assume that the number of cars taking a u-turn is negligible)
9. Each traffic light will have a min time, max time, and set time for the green. We will assume that the traffic lights cycle wherein at anytime connection to only one artery is open. The open artery allows cars to go to the other n-1 arteries. (We can develop other fancy schemes later – wherein straight traffic is allowed in two directions and then turn traffic is allowed in two directions …)
10. Another enhancement to the model in further research would be to add a rate at which cars in the queue move forward through the intersection.

The simulation was based on time steps where at each time step

1. Some cars are absorbed.
2. The rest of the cars are incremented on the road based on the speed limit of the road (some normal distribution can be used around the speed limit to figure out the exact vehicle speed)

3. The queue is updated
4. Based on the signal (if green) the cars move to the next intersection in the time step
5. Determine how many cars are added to each queue (Each car randomly decides which of the (n-1) paths it will join the appropriate queue)
6. Compute the average waiting time in the queue

Initial Results

Several intersection signal control algorithms were simulated in order to gather preliminary results. We assumed a uniform grid road network for these simulations; however, any road network can be simulated. Each intersection allows traffic flow in only one bi-directional flow through an intersection at a time, so there is no possibility for intersecting flows to collide. The choice of how long to maintain each flow and which flow to choose is the main task of the traffic signal control algorithm.

In our random signaling algorithm, traffic cycles are of equal duration for each flow through an intersection, however lights choose their next flow randomly. In our static signaling algorithm, traffic signals alternate, in a fixed order through all flows. In our counting signaling algorithm, traffic sensors count the number of cars in each possible flow through an intersection, whether traveling through the intersection, or queued due to a red light. The flow with the largest vehicle count is selected as green. In our predictive signaling algorithm, traffic signals receive information from their nearest neighbor intersection regarding the approaching vehicle count and allow the flow with the largest vehicle count to become green. The predictive signaling algorithm provides the best delay ratio (closest to 1.0). This provides some validation that a predictive, self-organizing technique has a potential for decreasing the average vehicle delay time.

Figure 1: Comparison of multiple traffic control strategies base on the traffic model developed.

The improvement in the delay ratio for a communicating and predictive signaling system shows promise; however, the algorithm needs to be developed further. In addition, different algorithms for self-organization need to be investigated in context of traffic signaling. We also need to understand the optimum rules for self-organization based on the type sensor data available in different locations. The current approach needs to be benchmarked against existing techniques. The algorithms also need to be tested for resilience in different anomalous traffic situations. For the benchmarking work, quantifiable metrics will be developed both for performance and resilience of the self-organizing transportation system. Finally we need to examine the impact of intelligent transport systems on self-organization where vehicles are embedded with sensors and are transmitting data to signals.

Conclusions and Future Work

The self-organized traffic light model reduces the complexity of the optimization through a series of local optimizations that leads to global synchronization rather than a very complex global optimization. Preliminary results from our analysis show a marked improvement in average vehicle delay using the self-organization approach. The basic model developed for the simulation validates some of our initial beliefs and provides impetus for pursuing this research further. Work is required for calibrating the simulation using real traffic data and refining the simulation as well as the self-organization algorithms further.

Inherent in the above model is the understanding that traffic lights will have sensing and communication capabilities. As we move forward, we need to understand how the traffic lights will sense traffic leaving the intersection and relay the information to the next signal as new technologies emerge? We also need to know the implications of technology on cost, accuracy, availability and reliability, and maintenance. Another key question that plays a big role is a self-organizing transport system is if car-car and car-signal communications will play a greater role in communication and coordination of traffic?