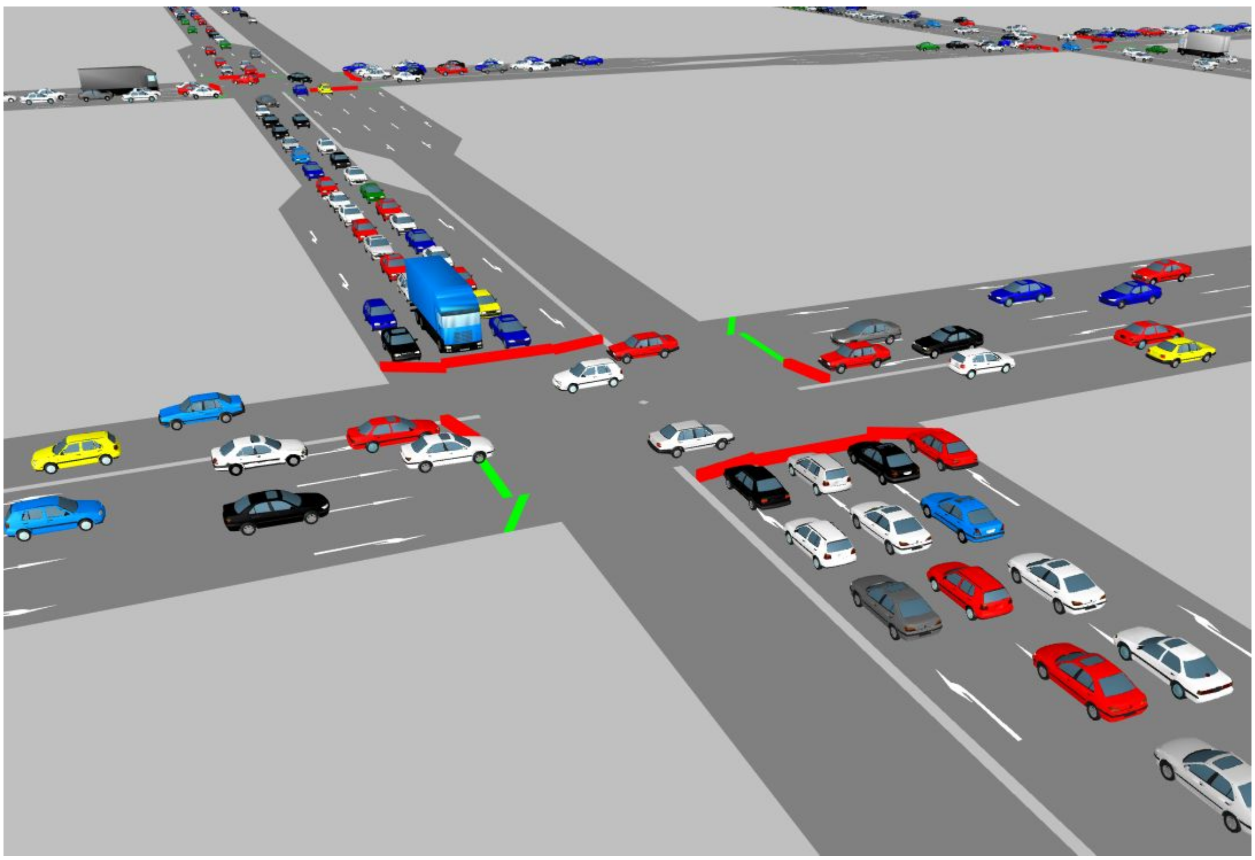
ADVANCE ENGINEERING MATHEMATICS

Course Project

Traffic Signal Coordination Under Oversaturated Condition



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Introduction

Traffic engineering is an important optimization problem that benefits the common people in day to day life. Normally the sufficiency of size of road and limited vehicle movements poses no problem but the violation of these conditions caused significant delays. The ever increasing volume of traffic in contemporary cities and the constraint of size of roads are not able to meet the requirements of smooth traffic flow. This has led to a very common phenomenon in current cities known as Oversaturation. Oversaturation occurs when a signalized intersection cannot process all arrived vehicles at the end of a green period; thus, a queue is developed and carried over to the next green period. If corrective steps are not taken, the growing queue blocks the intersection and reduce the capacity of intersection networks.

Providing an optimal solution for the oversaturation problem is a very cumbersome task. Since all the arterials in a network are interdependent and also time dependent, the optimal selection of all the variables in each traffic cycle becomes computationally costly. Since all the arterials in a network are interdependent and also time dependent, the optimal selection of all the variables in each traffic cycle becomes computationally costly.

One way to solve this problem could be to renewal and expansion of the already present traffic network. But this solution results in high cost of infrastructural modifications which is not always sensible. More efficient solution would be to improve mobility and efficiency of already present traffic network. Such traffic models involves use of efficient signal coordination.strategy. In last few decades various researchers have developed different signal coordination models with some more recent ones even tackling the problem of traffic-congestion/oversaturation. Such strategies generally involves maximization of vehicles processed by the queue or minimization of travel times of vehicles. The condition of over-saturation had been studied by various researchers past. Congestion was divided into two categories in form of saturation and over-saturation with saturation condition involving formation and growth of queue with a local delay effect that does not affect other intersections in the network. Earlier research involved development of control policies for minimization of travel costs which though worked well in under-saturated situations but failed miserably in over-saturated conditions. Later proposal used blockage and queue removal as the prime objective. Further strategy is to generate a set of green times such that the vehicles processed within the network in a given time gets maximized. This involves generation of green signals such that number of vehicles released at each signal are maximized during congested periods such that queue formation is minimized. Further offsets are generated for proper traffic progression. Testing of performance of different algorithms on a given model is necessary to find best optimization algorithm that should be applied. Luca and Putha have compared Genetic Algorithm and Ant Colony optimization on a given traffic model.

Formulation of traffic problem

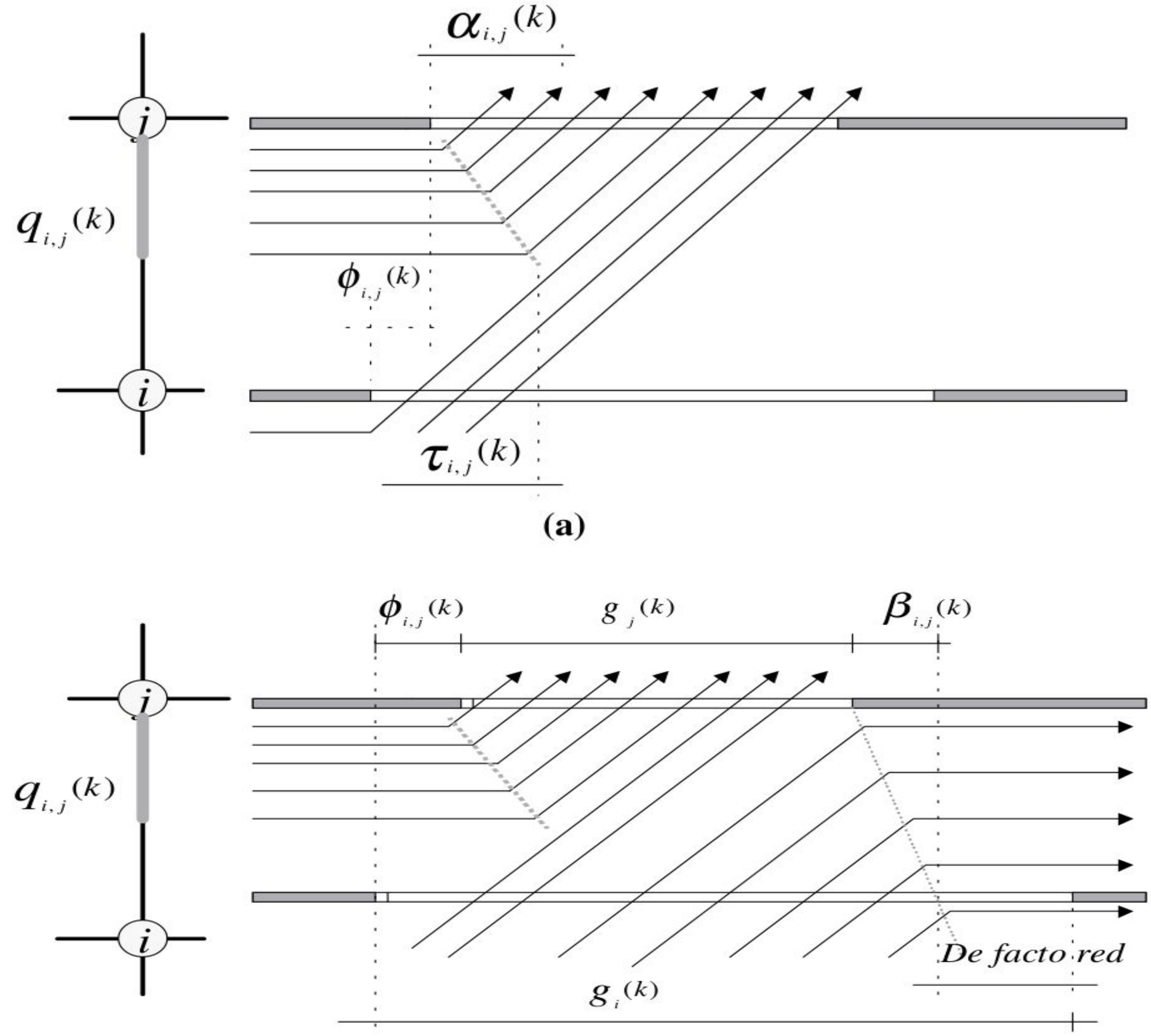

Fig 1:- Mechanism to explain the formation of optimal green time

Objective Function

Let Z be a network performance function as formulated by Equation 1. This function represents the number of vehicles processed by a signal network minus a network disutility function, which represents the occurrence of a queue on signal approaches along coordinated arterials.The overall goal is to maximize the net effect to process highest no of vehicles. K is the period of oversaturation in a cycle unit, and $D_{i,j}(k)$ is the departure flow at signal *j* coming from signal *i* at cycle *k*. A nonnegative weighting factor, $l_{i,j}$, is the distance between signal i and j, and $q_{i,j}(k)$ is the number of vehicles in the queue approaching signal j coming from signal i at the beginning of cycle k. L_p is a set of streets carrying coordinated movements, and $\delta_{i,j}(k)$ is a non-negative disutility factor whose values are determined based on a queue management strategy.

$$max\ z\ =\ \sum_{k}^{K}\sum_{i,j} l_{i,j}D_{i,j}(k)-\sum_{k}^{K}\sum_{i,j\in L_p}\delta_{i,j}(k)q_{i,j}(k) \qquad\qquad k>0, l_{i,j}>0$$

Offset and Green Time Constraints:

Coordinated Arterials

To provide traffic progression, two constraints need to be satisfied: efficient use of green time and de facto red avoidance.For efficient use of green time, an offset between two adjacent signals must be assigned so that the queue at the approach of downstream signals is cleared and the first vehicle released from upstream signals reaches the tail of the (moving) queue. This offset is called the ideal offset (ϕ). De facto red exists when the signal is green but traffic cannot proceed because of backed-up traffic on a receiving street. To avoid the de facto red situation, the effective green time for the upstream signal $g_i(k)$ should be less than the sum of the effective green time for the downstream signal $g_j(k)$, the offset between the two signals $\phi_{i,j}(k)$, and the time it takes for a stopping shock wave to propagate upstream, $\beta_{i,j}(k)$. For a two-signal system (signals i and j), as indicated in Figure 2a, the time required for the tail to start moving, α i, j (k), is calculated by dividing the queue length at the approach of signal j, q i, j (k), by the starting shock-wave speed.τ i, j (k) is the time required for the first vehicle in the released platoon from signal i to join the tail of the downstream platoon (as the tail has reached its desired speed). It is determined by the acceleration rate, the existence of queues at the approach of signal i, and the availability of an unoccupied space along the street connecting the two signals. Thus, for example, when the unoccupied space is long enough that it provides the platoon's first vehicle a sufficient distance to reach a free-flow speed, $\tau_{i,j}(k)$ is simply the ratio of the space to the free-flow speed. The ideal offset between signals i and j, $\varphi_{i,j}(k)$, is set equal to the difference between $\tau_{i,j}(k)$ and $\alpha_{i,j}(k)$ as formulated by Equation

$$\phi_{i,j}(k)\ =\ \tau_{i,j}(k)\ -\ \alpha_{i,j}(k)$$

For avoiding de Facto red situation, the volume of traffic arriving from downstream signal must get the same time to cross the signal as on the earlier intersection. Also,there is need of introduction of particular constant $\beta_{i,j}(k)$, time taken for the a stopping shock-wave to propagate upstream. This can be imagined as when the vehicles start travelling they need an extra space ,so the platoon size is greater than the queue size. Therefore, the sum of the green time of signal downstream, the offset and the shock-wave time should be greater the green time of the signal upstream as formulated by the following equation:

$$g_i(k)\leq g_j(k)+\phi_{i,j}(k)\ +\ \beta_{i,j}(k)$$

Green Time Constraints: Crossing Traffic

Non-coordinated Arterials

For the calculation of green times on the un-coordinated path($g_j^c(k)$), effective green times of the coordinated signals($g_j(k)$),the ideal offset $\phi_{i,j}(k)$, and the extended offset $ext\ \phi_{i,j}(k)$ between two adjacent signals and lost green time.

$$g_j^c(k) = ext\phi_{i,j}(k) + \phi_{i,j}(k+1) - g_i(k) \qquad (i,j) \in L_p$$

Lost green time (Δ) indicates the time during which the intersection is not effectively utilized for any movement. For example, when the signal for an approach turns from red to green, the driver of the vehicle which is in the front of the queue, will take some time to perceive the signal (usually called as reaction time) and some time will be lost before vehicle actually moves and gains speed. The extended offset is the value of time for which the next cycle at the uncoordinated signal takes place.

$$ext\phi_{i,j}(k) = C_i(k) + \phi_{i,j}(k+1) \qquad (i,j) \in L_p$$

$C_i(k)$ is the cycle length at an upstream intersection and $\phi_{i,j}(k+1)$ is the offset of next cycle.

Storage Capacity Constraints:

Non-coordinated Arterials

The queue along non-coordinated arterials must be less than the storage capacity of approach links. This constraint is to ensure that blockages on crossing (coordinated) arterials do not occur.

$$q_{i,j}(k) \le max\ q_{ij} \qquad (i,j) \in L_s, k = 1,..,K$$

The basic idea of the equation is that the size of the queue must not exceed the the total capacity of the given street. $q_{i,j}(k)$ is the queue length of the given cycle k at signal i,j and max $q_{i,j}$ is the maximum capacity if the street.

State Equations

In the normal state, it can be assumed the mode has enough space to process all the vehicles arriving, but in the case of oversaturation this the arrival rate $A_{i,j}(k)$ exceeds the departure rate $D_{i,j}(k)$ which leads to increase in the size of the queue. Also the size of the queue at present cycle is dependent on the previous cycle, Hence, the queue formation on k+1th cycle can be given as

$$q_{i,j}(k+1) = q_{i,j}(k) + A_{i,j}(k) - D_{i,j}(k) \qquad \forall\, j \in N, (i,j) \in L$$

Boundary Values

The green times of all the signals must be within the range of specified in the traffic standards. Also the value of initial queues at all the signals must be at the start of the cycle. These conditions can be represented by the following equations:

$$g_{min} \le g_i(k) \le g_{max} \qquad \forall j \in N;\ k = 1, ..., K$$

$$q_{i,j} = q_0 \qquad k = 0;\ \forall\ (i,j) \in L; k = 1, ..., K$$

Departure Volumes: Non-Coordinated Movements

Since the green times of the non-coordinated arterial are controlled by the coordinated ones, the offsets in this case can be non ideal. Two conditions can occur when non-ideal offsets are applied: wasted green and blockages. The duration of wasted green is a period of unused green time after the last vehicle in a queue is cleared until new arrivals pass intersections. The wasted green can occur if the start green is set too early relative to the upstream green initiation. In other words, green time is wasted when the magnitude of implied offsets is larger than the ideal offsets. Unused green time can also occur when excessive green time is assigned. Blockages, on the other hand, can occur if traffic is prevented from leaving upstream intersections because of the presence of a queue at downstream intersections. Blockages form when the stopping shock wave, caused by the midblock traffic, reaches upstream intersections and ends when the blockage is cleared. During this time, no vehicles are processed.

Stochastic Algorithms Based Procedures To Solve BSNP

Model Used

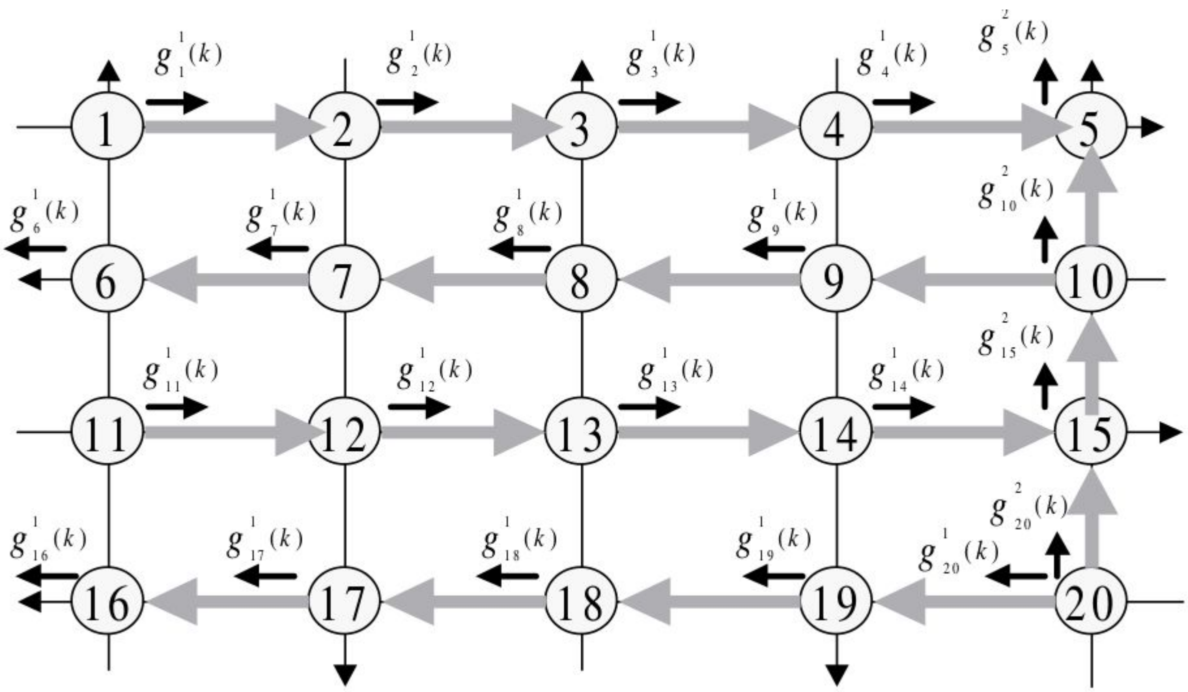

Fig 2:- Traffic Network model

The model used here a one-way arterial system with 20 intersections. Two arterials are assumed to carry very heavy traffic: 2,000 vehicles per hour per lane (vphpl). These are the northbound arterial from Signal 20 to Signal 5 and the eastbound arterial from Signal 10 to Signal 6. Furthermore, east-bound traffic enters the network at Signal 1 and Signal 11 with a flow rate of 1,800 vphpl, whereas westbound traffic enters the network at Signal 20 with a flow rate of 1,800 vphpl. These are defined as major movements. In addition, all minor traffic enters the network with a flow rate of 1,500 vphpl at Signals 2 and 4 for the south-bound traffic and at Signals 16 and 19 for northbound traffic. These entry flows are assumed constant during an oversaturated period. For coordinated movements, g_{max} = 90 and g_{min} = 30 s; for non-coordinated movements, g_{max} = 60 and g_{min} = 20 s. The number of arterial lanes is two. Speed limit, or desired speed, equals 40 ft/s, and vehicle acceleration is 4 ft/s 2 . Initial queues at all coordinated approaches are 20 vehicles per lane. Effective vehicle length is 25 ft. Starting and stopping shock-wave speeds are 16 and 14 ft/s, respectively.

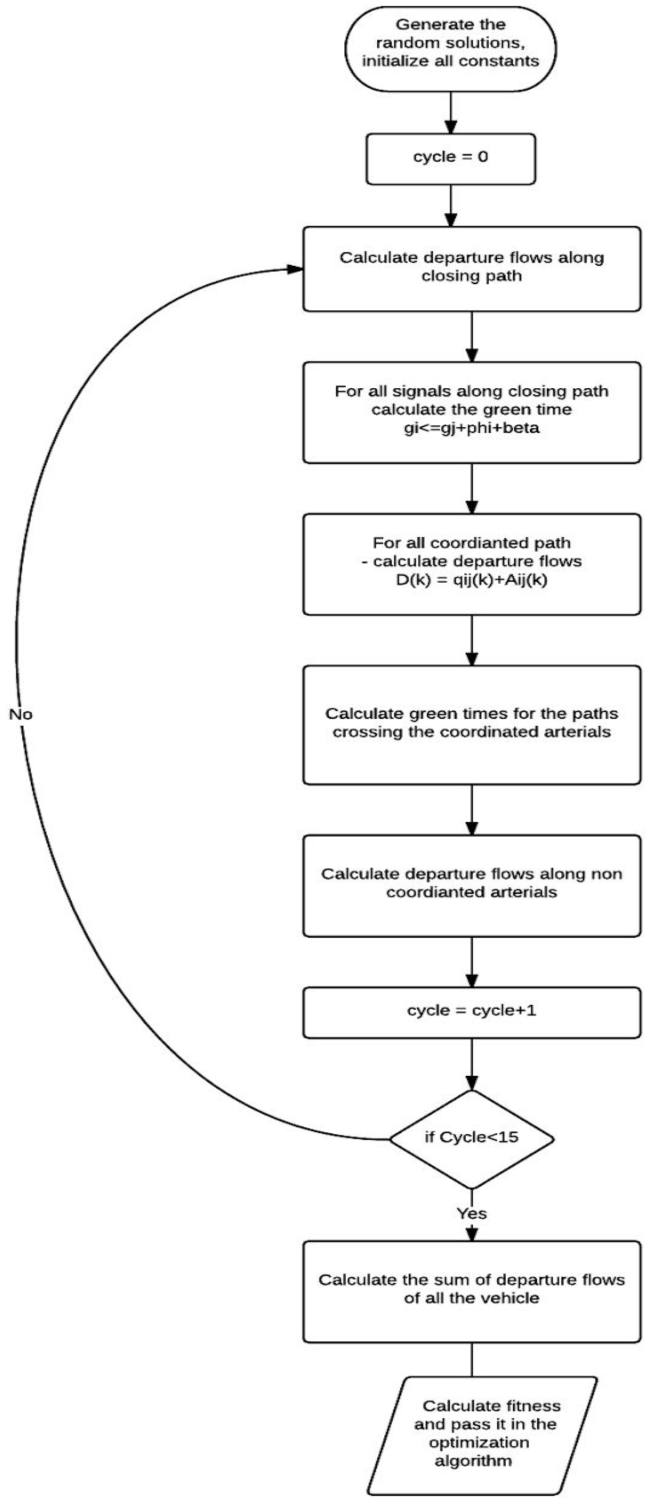

Fig 1:- Flowchart

Two algorithms were applied to find the optimal solution of the green times of all the cycles: Genetic Algorithm with tournament selection and Termite Spatial Correlation Algorithm.

Genetic Algorithm

A Genetic Algorithm is an optimization technique for global non-linear

optimization. All you need to supply is a way to represent your solutions and a "fitness function" that measures how good the solutions are. In computer science, lower fitness traditionally means better in minimization problem. A maximization problem can be converted into minimization problem by putting negative sign at the objective function.

In pseudocode the algorithm works like this:

1) Create a population of random solutions

2) Pick a few solutions and sort them according to fitness

3) Replace the worst solution with a new solution, which is either a copy of the best solution, a mutation (perturbation) of the best solution, an entirely new randomized solution or a cross between the two best solutions.

4) Check if you have a new global best fitness, if so, store the solution.

5) If too many iterations go by without improvement, the entire population might be stuck in a local minimum (a small hole, with a possible ravine somewhere else). If so, kill everyone and start over at 1.

6) Else, go to 2.

In step 2 the method of selection used is tournament selection. In this process, a group of individuals are selected randomly from the population and they are allowed to compete against each other. The most fit solution is allowed to reproduce. The population size selected here was 1000. The tourney size selected here is 10. The number of solutions that compete for the privilege of getting an offspring. A lower value means slower convergence, but lower than 3 would be silly. The function was evaluated for 5000 iterations.

When performing global optimization you want to be wary of too rapid convergence of your solution. Generally you will want to set parameters so that you get a solution slowly but surely. For most problems you can use the default parameters and one of the standard genome classes and just worry about your fitness function.

Termite Spatial Correlation inspired optimization (TSCO) algorithm:

TSCO is a swarm intelligence based heuristic optimization algorithm inspired by step/spatial correlation based movement exhibited by the population of termites.

The algorithm can be implemented in 3 main steps:

1. Attribute update phase: This phase involves updating various attributes like fitness, past velocities, correlation coefficients, best position and best fitness of each agent in the swarm such that these attributes can be used in the later phases of the algorithm.
2. Replacement and mutation phase: For this phase bad performing agents are killed and replaced with new agents by initializing them according to attributes of surviving agents in the swarm and mutating them.
3. Swarm update phase: This phase involves updating each agent's velocity and position in the search space so as to be used in the next iteration.

Objective Function using Constraints

All the equality constraints have been included in the equation model and for the inequality constraints, they have been included in the equation as penalty with constants μ_1, μ_2 and μ_3. The sum of all these represent the final objective function

$$max\ z = \sum_{k}^{K}\sum_{i,j} l_{i,j} D_{i,j}(k) - \sum_{k}^{K}\sum_{i,j\in L_p} \delta_{i,j}(k) q_{i,j}(k) - \mu_1 \left| \sum_{k=0}^{K} (g_i(k) - g_j(k) - \phi_{i,j}(k) - \beta_{i,j}(k)) \right|$$
$$- \mu_2 \sum_{k=0}^{K} (q_{i,j}(k) - max\ q_{i,j})$$

Results and Discussion

The cycle times of the different signals were calculated according to different optimization algorithms, namely Genetic and Termite spatial correlation algorithm. It can be clearly seen that the cycle lengths along all the arterials follow the reference signal i.e. signal 20, along the northbound and the eastbound signals. Fig 4 and Fig 5 shows the cycle times calculated by GA and TSCO along the closing path of the signals 5,10,15 and 20 respectively. It can be easily inferred that the offset in the cycle times calculated by GA is more than TSCO. This means the vehicles have to wait more at the intersection in the green time calculated by GA than TSCO. Fig 6 and Fig 7 are the plots of the cycle times of signals along eastbound arterial 20,19,18,17 and northbound arterial 2,7,13,17 respectively calculated by TSCO. Fig 8 and Fig 9 compare the convergence plots of GA and TSCO. It can be easily seen that TSCO has better convergence than GA. As depicted by fig 8 and 9 the total function evaluations taken by GA are much higher in comparison to TSCO as each iteration of GA takes 1000 function evaluations in comparison to 40 as taken by TSCO. Further TSCO has been evaluated for just 1000 iterations as compared to 20000 iterations as taken by GA algorithm. This clearly proves the efficiency of TSCO algorithm in solving oversaturated signal coordination problem.

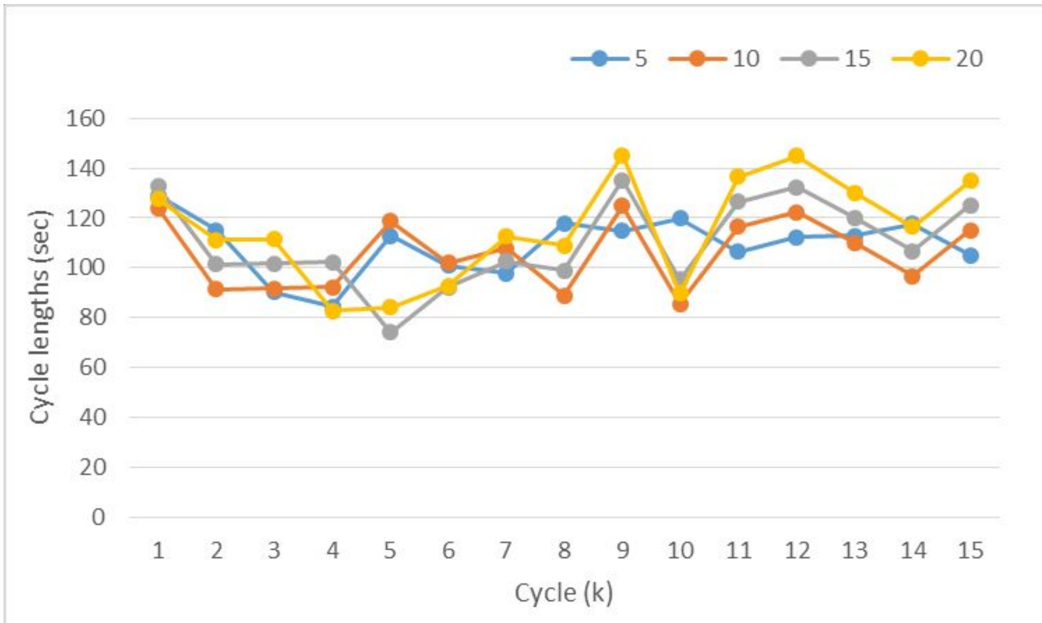

Fig 4:- Cycle times obtained by GA for signal 5 to 20

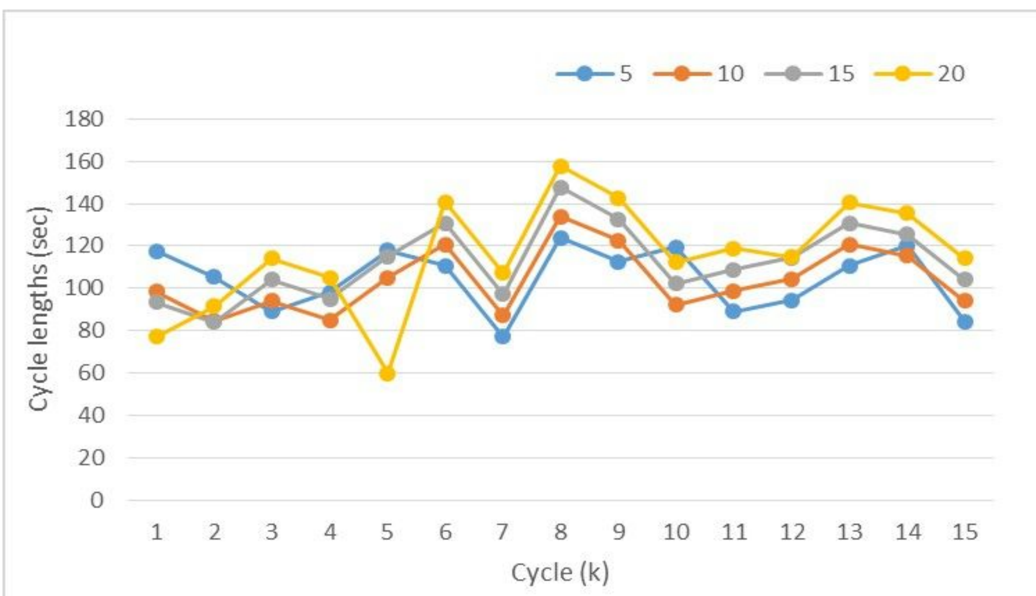

Fig 5:- Cycle times obtained by TSCO for signal 5 to 20

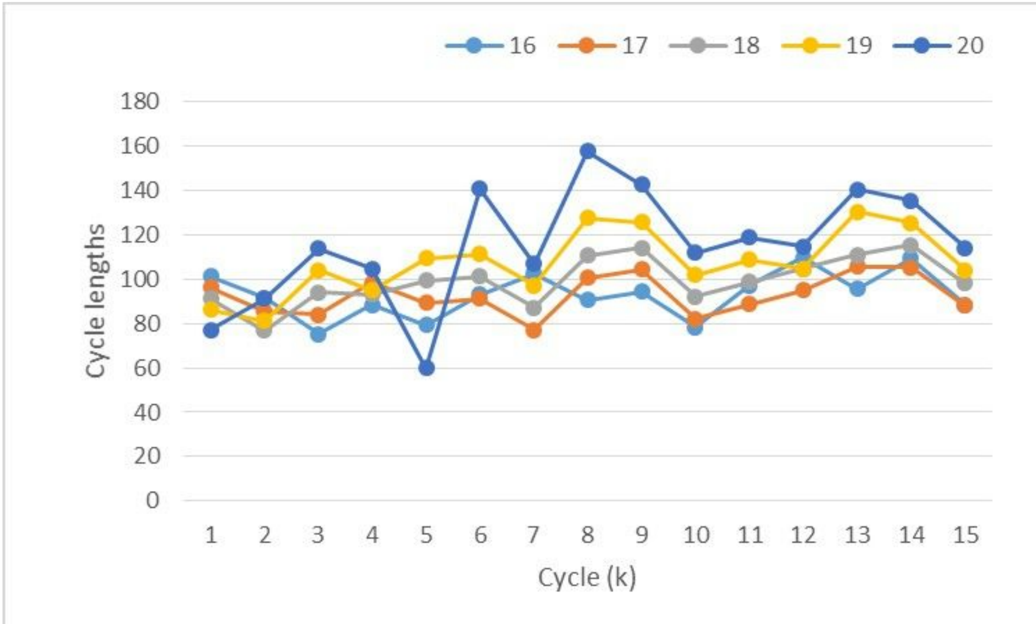

Fig 6:- Cycle times obtained by TSCO for signal 16 to 20

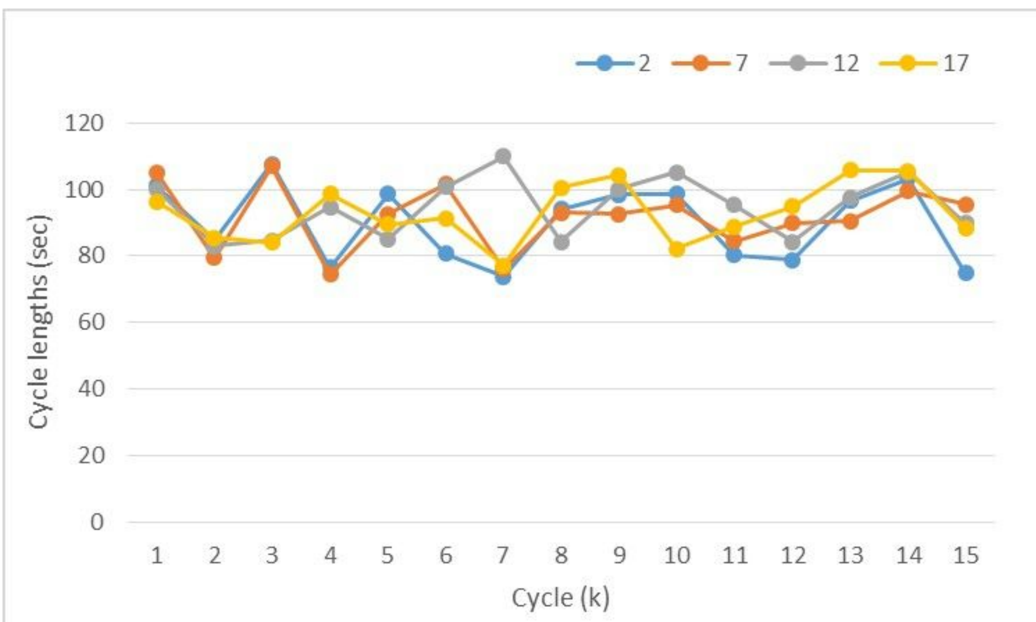

Fig 7:- Cycle times obtained by TSCO for signal 2 to 17

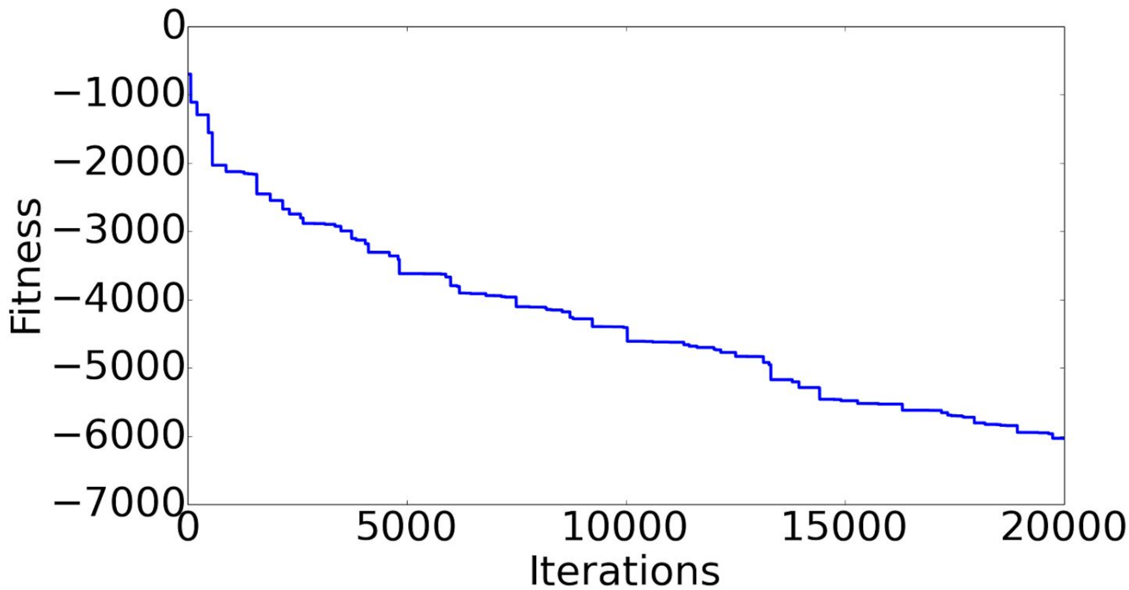

Fig 8:- GA convergence curves

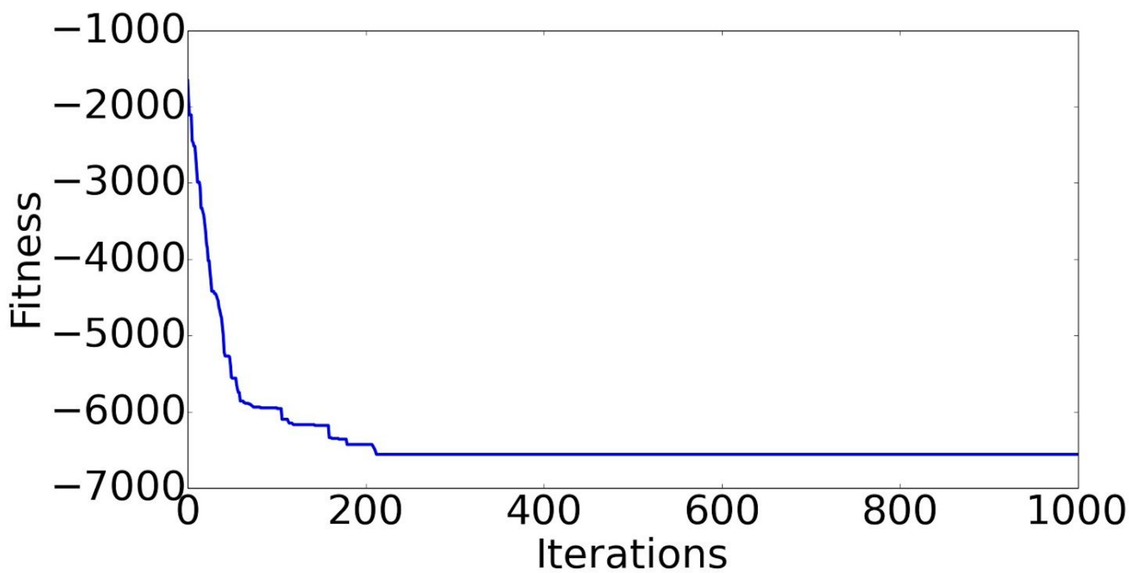

Fig 9:- TSCO convergence curves

Conclusion and Future Work

Traffic congestion occurs when the queue length at the intersection exceeds the capacity of the street. This blocks the traffic coming from the upstream signals. There is utmost need of developing an efficient algorithm for handling this situation with increase in urban development. This paper compares the two algorithms on a benchmark optimization problem of traffic signal coordination under over-saturated conditions. In this paper it was easily found that TSCO algorithm performance is better than the traditional GA with tournament selection as it requires less number of function evaluation than GA. This problem can be further be analysed by application more number of different optimization algorithms. A real time traffic model can be included which can have all the arterials as coordinated arterials. For decreasing the time complexity parallel computing for function evaluation can also be done. Many similar type of problems also exists like data routing in communication and air traffic control etc. These techniques can also be applied to such problems also.

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