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Optimizing Traffic Signal Cycle Lengths by Exploiting Already Deployed Smart Antenna Technology (OTSAT)

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Abstract-Traffic light control and coordination is a critical function in today's busy roadways. Typically traffic lights have been shifting from fixed timing to ones that are based on a variety of sensors. However, several shortcomings have been identified when considering these different approaches. In this paper, we propose a scheme for smart dynamic traffic lights that can adapt their signaling time according to the traffic density by exploiting Direction of Arrival(DoA) and Timing Advance information transmitted from cell-phones(carried by the car drivers)to the Smart Antenna installed on cellular base stations. The OTSAT is designed to address these challenges as it adaptively controls the traffic light timings. It dynamically manages the different traffic patterns and has the potential to attain the queuing reduction efficiency from 22% to 100% depending upon different traffic scenarios. Consequently, such an approach would reduce fuel consumption and pollution by avoiding queue (idling) on traffic lights.

Keywords-Angle of Arrival (AoA), Cell-phone, Direction of Arrival (DoA),Smart Antenna,3G/4G, traffic light management

I. INTRODUCTION

Mobile wireless service providers are deploying Smart Antenna technology in densely populated urban areas, where demand for high-speed data services is high. Smart Antenna offer an increase of three times for Time Division Multiple Access (TDMA) systems, five times for Code Division Multiple Access (CDMA) systems and much higher improvements for future systems (e.g. 100 Gbps) as the base stations begin to support Smart Antenna technologies [i]. Also Smart Antenna offers a mixed service capacity gain of more than 100%,and hence the required number of base stations can be reduced to less than a half [ii].

In recent years, there has been a shift from typical fixed timing traffic signaling to sensor based dynamic and coordinated control traffic signaling. In both of these approaches, smart traffic lights adapt the signaling time for green and red according to traffic density [iii]. However, these solutions are (a) complicated because they involve direct communication between vehicles and traffic lights and (b) relatively expensive because they require dedicated components such as buried induction coils, cameras, sensors, optical fibers and computers, which also often have high installation cost since they require road construction.

Many intersections have some sort of mechanism for detecting vehicles as they approach the intersection. Most common mechanisms are based on induction loops [iv]. These are buried in the roadway and detect vehicles through changes in their magnetic field created by the metal body of passing vehicles. However, these are not cost effective. Other common methods are video detection which uses pixilation [v], microwave detection, and infrared detection among others [vi]. Some intersections have detectors on both the major and minor streets (fully actuated) and a controller has a programmed time to service all movements every cycle. Some intersections have the detectors on minor streets and major street left turns only (partly actuated). In such a setup, the major streets are programmed to operate at a fixed time every cycle and a controller services the other movements only when there is higher demand. These approaches require installation of new hardware at each intersection (e.g. sensors) and may provide a partial solution, i.e. on the major city roadways, as they can be cost prohibitive [vii]. Wireless sensor based systems, which provide road construction free deployment, have been proposed as an alternative technology [viii]. However cost of the sensors make it unviable. Another research approach uses synchronized traffic lights system to smooth traffic flow [ix]. This system requires synchronization among traffic lights and strict observance of speed limits.

An adaptive traffic signaling approach through smart phones using Floating Car Data to regulate traffic light systems, which requires instrumented vehicles (equipped with GNSS sensor and or local radio system) and the local radio signal emitter needs to be appropriately placed on the side of road network allowing the localization of instrumented vehicles when satellite localization is not usable. Also smartphones must have a dedicated software, able to identify the vehicle position and communicate to the central control server[x].

We have previously proposed a technique that exploits the Smart Antenna technology for traffic light signaling optimization [xi-xii]. However it had few limitations for e.g. we considered that each vehicle carries only one cell-phone and the pedestrians on the walkways carrying cell-phones do not add any potential error. The objective of this paper is to address the above noted shortcomings and the limitations of our previous publications. The proposed design involves the following "4Cs":

a. **C**ollection and processing of valuable information from the Smart Antenna.
b. **C**alculation of total number of cell-phones and their specific location around intersections.
c. **C**onveyances of the above information to a dedicated sever.
d. **C**ommunication of the server with the traffic lights to adaptively adjust the signaling times so that the waiting time in front of red traffic light may be reduced as effectively as possible.

The rest of the paper is divided into four sections. Section II, provides an overview of Smart Antenna technology. Section III describes the proposed system. Section IV, presents the analysis results and Section V, conclusion.

II. Smart Antenna Technology

A Smart Antenna system in telecommunication context performs the following functions:

a. Estimates the Direction of Arrival (DoA) of all incoming signals including the interfering signals and the multipath signals using the DoA algorithms.
b. Identifies the desired user signal and separates it from the rest of the unwanted incoming signals.
c. Steers a beam in the direction of the desired signal to track the user as he moves, while placing nulls at interfering signal directions by constantly updating the complex weights.

These functions are further described below:

Adaptive Array Antenna: The Smart Antenna System is capable of automatically changing the direction of its radiation patterns in spatially sensitive manner in response to its signal environment. It consists of a set of radiating elements arranged in the form of an array (thus named adaptive array antennas), and smart signal processing algorithms to identify the DoA of the signal. The system uses this, and some additional information, to calculate beam forming vectors to track and locate the antenna beam on the cell-phone units. Since continuous steering of the beam is required as the cell-phone moves, high interaction between the cell-phone unit and base station is required. Traditional adaptive array systems enable a base station to form a main lobe toward individual users and attempt to reject interference from outside of the main lobe.

Direction of Arrival (DoA): The Smart Antenna system estimates the DoA of the signal using techniques such as Multiple Signal Classification (MUSIC), Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) algorithms [xiii], Matrix Pencil (MP) methods [xiv], or one of their derivatives. They involve the findings of a spatial spectrum of the antenna/sensor array and calculating the DoA from the peaks of this spectrum. These calculations are computationally intensive. Matrix Pencil is very efficient in case of real time systems and under the correlated sources.

Beamforming: It is the method used to create the radiation pattern of the antenna array by constructively adding the phases of the signals in the direction of the desired targets/cell-phones, and nullifying the pattern of the targets/cell-phones which are undesired/ interfering targets. This can be done with a simple finite impulse response (FIR) tapped delay line filter (FIR filters are digital filters used in Digital Signal Processing (DSP) applications). The weights of the FIR filter may also be changed adaptively and used to provide optimal beam forming and actual beam pattern formed. The steepest descent and the LMS (Least mean square) [xv] are typical algorithms. The use of high-performance Digital Signal Processing (DSP), Embedded Processors (EPs) and Logic Elements (LEs) make the Beamforming adaptive.

Down Conversion: The signal from each receive antenna is first down converted to baseband, processed by the matched filter-multipath estimator, and accordingly assigned to different rake fingers. The Beamforming unit on each rake finger then calculates the corresponding (i) beam former weights and (ii) channel estimates, using the pilot symbols that have been transmitted through the Dedicated Physical Data Channel (DPDCH). The QR decomposition-based Recursive Least squares (QRD-RLS) algorithm is selected as the weight update algorithm because for its fast convergence and good numerical properties [xvi]. The updated beam former weights are then used for multiplication with the data that has been transmitted through the DPDCH. Maximal Ratio Combining (MRC) of the signals from all fingers is then performed to yield the final soft estimate of the DPDCH data.

III. Description of the Proposed System

The proposed solution is based on exploiting Smart Antennas for optimizing traffic signaling times using Smart Antenna Technology (OTSAT). The overall concept is depicted in Fig. 1. As the title reveals, our objective to exploit the Smart Antenna technology to achieve the optimization in traffic light duration, which is also explained in "Advanced algorithm for position location" [xvii]. Finding optimal signal timing for a large number of traffic signals is challenging because of the exponential increase in number of vehicles, and extensions in the road infrastructure. The OTSAT is designed to address these challenges, as it adaptively controls the traffic light timings and dynamically manages the different traffic patterns by using an efficient algorithm. The conceptual model and the algorithm is explained in the following paragraphs.

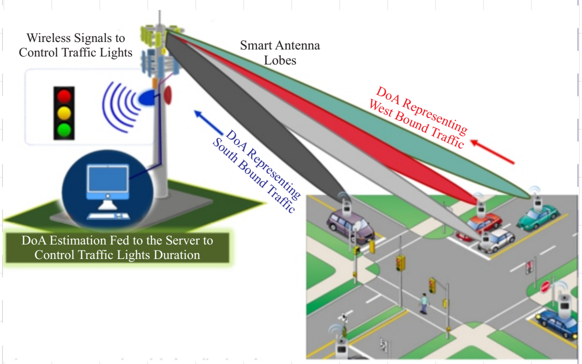

Fig. 1. Conceptual model of the application of Smart Antenna traffic light.

The proposed OTSAT system consists of the following three logical components:

1. Traffic Statistics Collector (TSC)
2. Traffic-light Duration Estimator (TDE)
3. Traffic-light Duration Controller (TDC)

However, physically these three components can be housed in a single entity or server. The functions of these components, in context with the algorithm shown in Fig. 2, are explained as follows:

1. Traffic Statistics Collector (TSC)

TSC is a part of the OTSAT that is depicted by the blocks B and C in Fig. 2. We consider one TSC and few intersections to illustrate some selected scenarios; however, the system can be deployed over the entire city for all types of intersections/scenarios. The four key functions performed by TSC are listed below:

(i) The TSC initially populates the latitude and longitude (from now on referred as LatLong) coordinates information about the:
  a) Location of traffic lights
  b) The extends of the paved roadways and
  c) The extends of the walkways

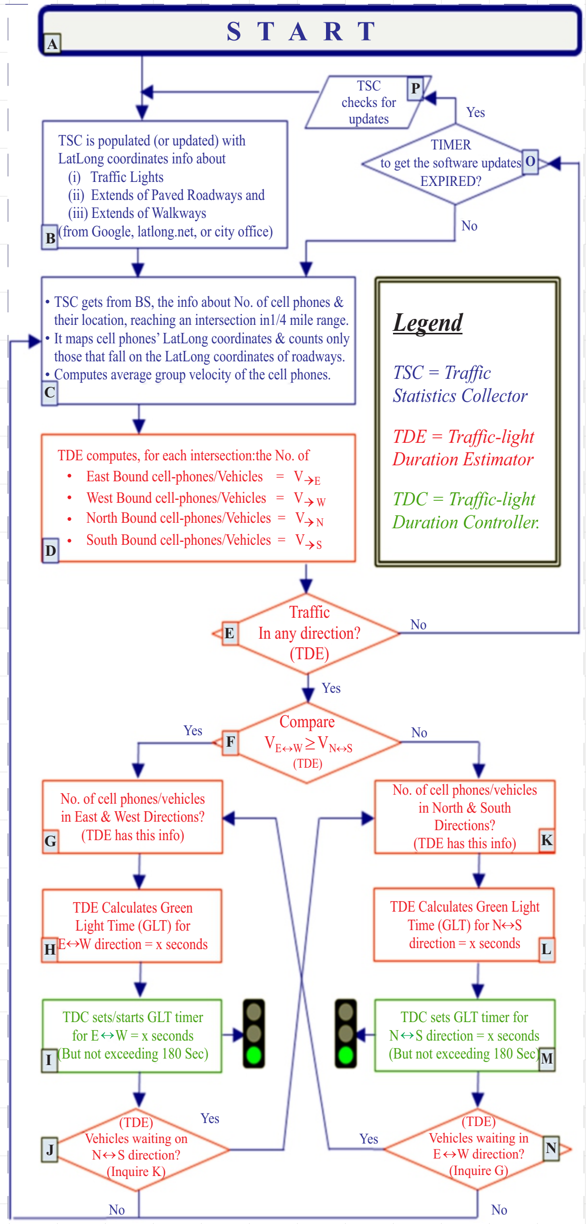

Fig. 2. OTSAT approach describing the functionality and optimization process

(ii) The TSC retrieves the information from the Base Station (Smart Antenna) about the number of cell-phones and their location (in terms of Angle of Arrival-AoA, Timing Advance, etc.) approaching a specific traffic intersection in ¼ mile radius.

(iii) The TSC converts the cell-phones location information into LatLong coordinate format.

(iv) The TSC maps LatLong coordinates of cell-phones (available from step (iii) above) with the geo LatLong coordinates of the Roadways (available from step (i) above), and counts only those cell-phones which fall within the extends of the LatLong coordinates of Paved Roadways. It also counts as to how many cell-phones are in each lane (including through lanes, right turn lanes, left turn lanes).

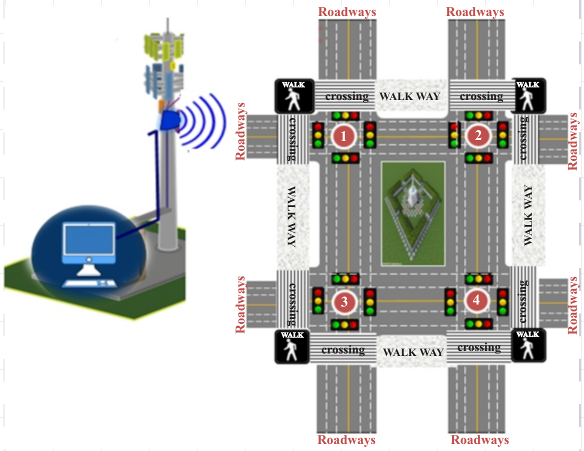

Fig. 3. OTSAT approach depicting Multiple Intersections (MI)

The TSC initially populates, its database by acquiring the LatLong coordinates information about all the traffic lights location, as well as the length and extend of paved roadways, intersections, and concrete/paved walkways from google.com, the latlong.net or local public administrations to get the correct identification of the roadways and walkways extends, the traffic laws implemented on each intersection, such as number of through traffic lanes, number of lanes with indications of No Turn Allowed, Right Turn Allowed/Not Allowed on red etc. for the proper identification of a cell-phone as one carried by a pedestrian or one carried by a person in a vehicles.

For example, the LatLong coordinates for the highlighted rectangular area highlighted as ABCD in Fig. 4, acquired from http://www.latlong.net/convert-address-to-lat-long.html, shows the intersection of Rhawn and VerreeStr, Philadelphia PA. These are points A(40.072719, -75.076080), point B(40.072844, -75.075984), point C(40.072663, -75.076040) and point D(40.072776, -75.075909). Moving the mouse over the image on the actual URL, one can notice that each point on the map (Including Traffic Lights, Paved Roadways, Walkways, buildings, Parks, etc.) can be defined with its associated LatLong coordinates.

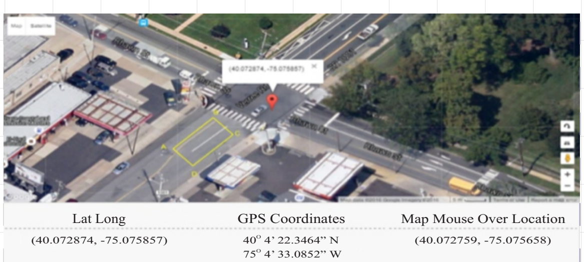

Fig. 4. Screen Print for Rhawn-Verree intersection in Philadelphia, PA, (http://www.latlong.net/convert address-to-lat-long.html).

The second task of the TSC is to extract continuously and recurrently the following information from the DSP (Digital Signal Processor) of the Smart Antenna in the Base Station for the uplink direction only[xviii-xix].

In the case of the 4G/LTE Base Station (eNodeB) the information retrieved is:

- Timing Advance (TADV)
- Angle/Direction of Arrival (AoA/DoA)
- E-UTRA Measurement Results List
- Evolved Cell Global Identifier (ECGI)/Physical Cell ID
- Reference signal received power (RSRP)
- Reference Signal Received Quality (RSRQ)
- UE (User Equipment) Receive – Transmit time difference

In case of the 3G/CDMA Base Station (NodeB) the information retrieved is:

- Timing Advance (TADV)
- Angle/Direction of Arrival (AoA/DoA)
- UTRA Measurement Results List
- UTRAN Physical ID
- Common Pilot Channel
- Received Signal Code Power (RSCP)
- Common Pilot Channel Ec/Io (the ratio of the received energy per chip and the interference level).

The TSC extracts the above noted information (ii) continuously and recurrently from DSP every 0.5 ms with that, a vehicle tracking resolution of about 0.5m can be achieved even if the vehicle is traveling at 45 mph. In Smart Antenna, the received signal (containing the above information) from the spatially distributed antenna elements, is down converted to intermediate frequencies, and then into digital format. The DSP processes it using different algorithms such as explained in[xx].

The third task of the TSC is to translate the above noted information extracted from the Smart Antenna's DSP, into the LatLong coordinates format. Thus the TSC knows the location of all cell-phones in terms of LatLong coordinates format. Finally the TSC maps LatLong coordinates of cell-phones with the LatLong coordinates of the roadways, walkways, buildings, parks, etc. and counts the cell-phones which happen to fall on the LatLong coordinates of Paved Roadways only, whereas it ignores all other, as it assumes they are cell-phones of pedestrians. From the available information, the TSC also knows the rate at which the cell-phones are traversing the geo LatLong coordinates (distance), thus the TSC can also compute the speed of the cell-phones and hence the vehicles as well.

In essence, the TSC contains all the information required to compute the speed (velocity) and direction of the cell-phones/Vehicles, and demarcate them as East, West, North and South bound with respect to each traffic light at each intersection.

The accuracy of the proposed system depends on the accuracy of the LatLong coordinates of cell-phones or in other words the accuracy of AoA/DoA acquired from the Smart Antenna. The proposed system's accuracy is between 1 to 5 cm, as currently deployed algorithms offer high level, commercial grade precision, demanded by the Smart Antenna. Among these Narrowband Model, MUSIC, ESPRIT, and specially Improved Orthogonal Matching Pursuit (IOMP) algorithms, proposed in [xvii, xx-xxi], offer high resolution DoA Estimation (i.e. the angle should be partitioned as fine as possible). This algorithm firstly obtains the initial estimated DOAs and then, utilizes an Iterative Local Searching process to improve DOA estimation accuracy. The simulation results from the above references demonstrate that the algorithm can distinguish two sources from the adjacent DOAs. Further, the Smart Antenna used for cell-phone communication demand higher location precision in both uplink, as well as in downlink, because Smart Antenna have to accurately locate the cell-phones. In our proposed application, the Smart Antenna demand accuracy in uplink direction only. Since the proposed technique does not mandate a two way precision, it further guarantees the desirable accuracy needed to distinguish closely placed cell-phones/Vehicles in adjacent lanes, or the walkways from the roadways, or passengers sitting in the same vehicle.

2. *Traffic-light Duration Estimator (TDE)*

The TDE (See Blocks D, E, F, G, H, J, K, L and M in Fig.2) is the integral part of the Server. The TDE collects the information from the TSC and performs the following tasks for any given intersection:

1. It computes and segregates the number of:
   East bound cell-phones/Vehicles $=V_{\rightarrow E}$
   West bound cell-phones/Vehicles $=V_{\rightarrow W}$
   North bound cell-phones/Vehicles $=V_{\rightarrow N}$
   South bound cell-phones/Vehicles $=V_{\rightarrow S}$
   Sum of East and Westbound cell-phones/Vehicles $=V_{E\leftrightarrow W}$
   Sum of North and Southbound cell-phones/ Vehicles$=V_{N\leftrightarrow S}$

   These are the number of cell-phones/Vehicles either stopped in front of traffic light or moving towards the traffic light at any velocity, but in the range of ¼ mile radius measured from the intersection.
2. It compares the two directions, East-West ($V_{E\leftrightarrow W}$) versus North-South ($V_{N\leftrightarrow S}$)and selects the one with greater number of cell-phones/Vehicles.
3. It computes the Green Light Time (GLT) for the direction with greater number of cell-phones/ Vehicles (as selected in step 2 above) and multiplying it with the time needed for one vehicle to cross the intersection, as per following formulae.

$$GLT_{E\leftrightarrow W} = \left(V(LMax)_{E\leftrightarrow W}\right) \text{x } TTP = x \text{ sec}$$

and

$$GLT_{N\leftrightarrow S} = \left(V(LMax)_{N\leftrightarrow S}\right) \text{x } TTP = x \text{ sec}$$

where

GLT = Green Light Time

$V(L_{Max})_{E\leftrightarrow W}$ = The Farthest vehicle in the range of East or West at any given intersection

$V(L_{Max})_{N\leftrightarrow S}$ = The Farthest vehicle in the range of Northor Southat any given intersection.

TTP = Time required by one vehicle to cross the intersection.

TTP is dynamically calculated by TTP Calculator using $T= S/V$, where $S(m)$ is the length of a given intersection and V(mi/sec) is the average group velocity of the vehicles at that intersection. The average group velocity (V) is calculated by using $V = S_V/T_V$, where S_V is estimated by using LatLong coordinates between the intersection and the last vehicle in the range at a given intersection and T_V is time taken to traverse the distance S_V. The above formulae are customized for each traffic intersection to suit particular requirements, dimensions, and conditions of that intersection. To check the validity of above formulae, and the working of algorithm, a few scenarios are discussed below:

<u>Scenario 1</u>: In this scenario we assume that the red light towards East-West bound and vehicles are stopped (i.e. their current velocity is zero mph). Let's consider the length of intersection is 300 ft. and has two lanes. East-West($V_{E\leftrightarrow W}$) bound, has greater number of cars i.e. 25 vehicles (more specifically 15 vehicles are East bound ($V_{\rightarrow E}$), where *LMax*(10 vehicles) and 10 vehicles at West ($V_{\rightarrow W}$) bound), against 15 vehicles in North-South ($V_{N\leftrightarrow S}$) bound. Vehicles will start moving slowly, since waiting at red light and will resume with an average group velocity of 25 mph i.e. (25×5280 = 132,000 ft/hr). Thus the TTP would be 300/132,000 = 8.1 s and The GLT would be assigned for 80.10 s (10 x 8.1 s) to clear the traffic for East-West ($V_{E\leftrightarrow W}$) bound. On the other hand the traffic light would be red for 80.10 s for North-South bound. In this case, the algorithm will follow the blocks C, D, E, F, G, H, I, and jump to K, L, M and N.

<u>Scenario 2</u>: Assume that there is already a green light and traffic is moving in North-South ($V_{N\leftrightarrow S}$) bound with Average group velocity of 45mph. Let's consider the length of intersection is 300 ft. with two lanes. North-South ($V_{N\leftrightarrow S}$) has heavy traffic i.e. 90 vehicles, with 60 vehicles North bound ($V_{\rightarrow N}$), where *LMax*(40 vehicles) and 30 vehicles in South bound ($V_{\rightarrow S}$). Thus the TTP would be 300/237,600 = 4.5 s and The GLT would be assigned for 180 s (40 x 4.5 s) for North-South ($V_{N\leftrightarrow S}$) bound. If we assume that there are no vehicles in East-West ($V_{E\leftrightarrow W}$) bound at all, the algorithm will again follow the blocks C, D, E, F, K, L, M, N, and back to C and continue extend the GLT for North-South ($V_{N\leftrightarrow S}$) bound to clear off the traffic until there is any vehicle on an alternate direction and threshold time of 180s (set limit) expires for waiting in front of red-light.

<u>Scenario 3:</u> Assume that there is already a green light and traffic is moving in East-West ($V_{E\leftrightarrow W}$) bound. Let's consider the length of intersection is 400 ft. and has two lanes. East-West ($V_{E\leftrightarrow W}$) bound has greater number of vehicles i.e. 90 (70 vehicles east bound ($V_{\rightarrow E}$), where *LMax*(50) and 20 vehicles west bound ($V_{\rightarrow W}$), with the average group velocity of 45 mph i.e. (45×5280 = 237,600 ft/hr). Thus the TTP would be 400/237,600 = 6.0 s and the GLT would have been assigned for 300 s (50 x 6.0 s) for East-West ($V_{E\leftrightarrow W}$) bound. If there are any vehicles in North-South ($V_{N\leftrightarrow S}$) bound (say 4 vehicles North bound ($V_{\rightarrow N}$) and, zero vehicles on South ($V_{\rightarrow S}$), the algorithm will allow a maximum GLT to be 180 s(max. limit) to East-West($V_{E\leftrightarrow W}$) bound instead of 300s and follow the blocks C, D, E, F, G, H, I, and jump to K, L, M, N and turn GLT of 24s (4 x 6.0s) for North-South($V_{N\leftrightarrow S}$) bound and then continue with G, H, I, J, and back C.

3. *Traffic-light Duration Controller (TDC)*

The TDC receives the recently calculated GLT information from TDE (See Blocks I and M in Fig. 2). It sets the Green Light Time for *x* s based on real traffic.

Block O and P in the algorithm are to cater for the addition of new traffic lights, construction of new paved roadways, and new concrete/paved walkways. These updates are obtained from Google, Latlong.net or local administration to update the TSC.

IV. ANALYSIS RESULTS

Since our study is theoretical and prototype, the TSC presently is not connected to any base station (more specifically the DSP of the Smart Antenna). The TSC emulates the traffic generation for all directions through the static code we have developed in Java, where vehicles are created randomly and performs the tasks as per algorithm (Fig. 2). We have optimized our analysis by generating random traffic through simulator at multiple intersections (Fig. 3), while considering scenarios(1,2 and 3) mentioned above in section III for OTSAT compared to Conventional method (for 60s) for 15 iterations (i.e. a full cycle of traffic light for which signal light stays green or red for East-West and North-South).One may ask why we took 60 seconds of green for each direction in conventional traffic signals. Based on National Association of City Transportation Officials [xxii]. The major corridor receives almost four times as much green time (96 seconds) as the minor streets (24 seconds). So we have taken an average (96 +24 = 120/2 = 60 seconds).

In the following paragraphs we analyze the scenarios to establish that the GLT is not fixed for OTSAT, but varies dynamically for each iteration (Fig. 5). The dynamic adjustment of GLT considering several factors (such as Number of vehicles traveling in a certain direction, their group velocity, the width of the intersection, and the most number of vehicles (*LMax*) etc.), plays a vital role in achieving the efficiencies we claim over conventional method, where the traffic light remains unnecessarily green or red until the fixed duration timer expires. Whereas the green light time for conventional methods is considered as fixed for 60s.

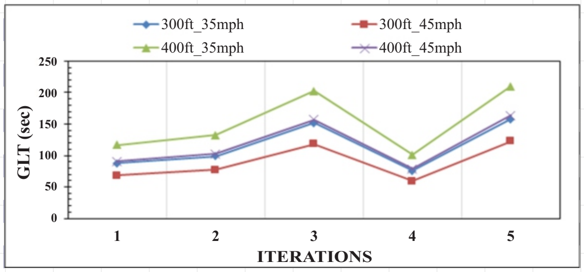

Fig. 5. Dynamic GLT calculation for OTSAT

Considering the light traffic volume Fig. 6, shows the GLT assigned for OTSAT versus conventional for East-West($V_{E\leftrightarrow W}$) and North-South($V_{N\leftrightarrow S}$) bound. Let's ponder on the first iteration for 20 and 21 cell-phones/Vehicles, where OTSAT calculates the GLT as 48.6 s, 27s, and 36 s for East-West ($V_{E\leftrightarrow W}$) bound and 56.7s, 0s, and 42s for North-South ($V_{N\leftrightarrow S}$) bound for Scenarios (1, 2 and 3) respectively to clear off the traffic, while the GLT for the conventional method is fixed for 60s. For the situation under discussion, the waste time (i.e. the time that vehicles waste in front of a red light, while the light is unnecessarily green on an alternate direction), OTSAT not only helps to avoid the waste time of an average is 48%, 85% and 62% for the above considered scenarios respectively but also reduce the queuing efficiency of 100% compared to conventional method.

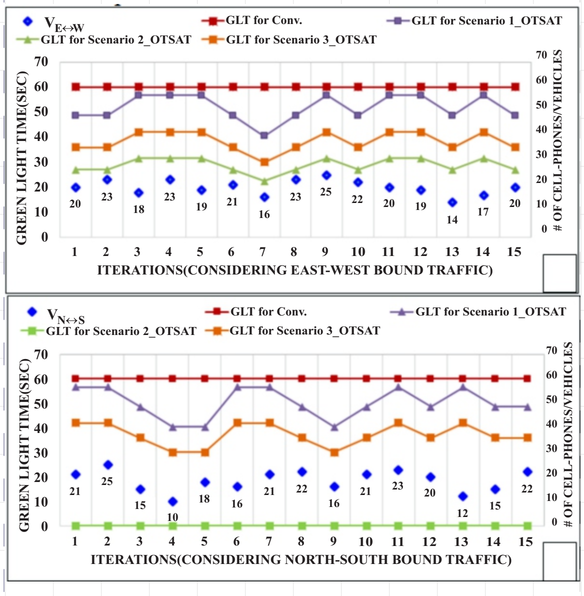

Fig. 6. GLT for Conventional and OTSAT for light traffic a) East-West and b) North-South bound

Considering moderate traffic volume (Fig. 7) show the GLT for East-West ($V_{E\leftrightarrow W}$)and North-

South($V_{N\leftrightarrow S}$) bound.

Let's ponder on the first iteration when there are 51 cell-phones/Vehicles in East-West ($V_{E\leftrightarrow W}$) and 48 in North-South ($V_{N\leftrightarrow S}$) bound. OTSAT calculates the GLT as 137.7 s, 76.5 s, and 102 s and 113.4 s, 0 s, and 84 s for 1st, 2nd, and 3rd scenarios to clear off the East-West ($V_{E\leftrightarrow W}$) bound and North-South ($V_{N\leftrightarrow S}$) bound traffic respectively, while the green light time for conventional methods remains fixed(60 s) every iteration. Likewise the GLT is been calculated for remaining iterations.

We have also evaluated all above scenarios for heavy traffic and observed that OTSAT compared to conventional method (60s), offers queue reduction efficiency of an average of 67% (refer to Table I).

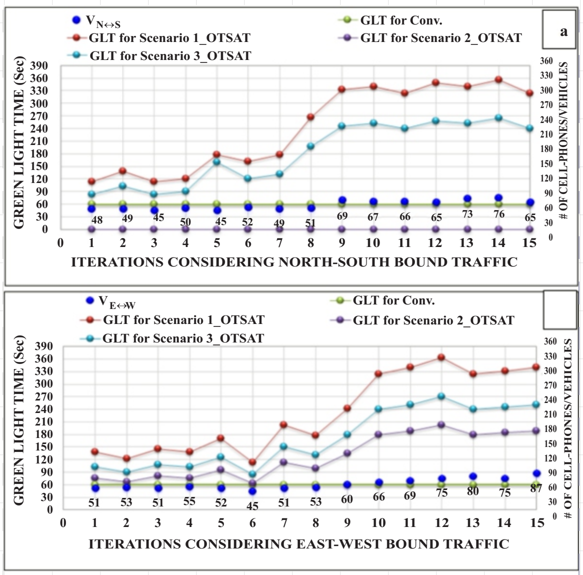

Fig.7. GLT for Conventional and OTSAT for moderate traffica) East-West and b) North-South bound

Fig. 8 shows the queue length of cell-phones/Vehicles for East-West ($V_{E\leftrightarrow W}$) bound and North-South ($V_{N\leftrightarrow S}$) bound. Fig. 8(a) shows that in iteration #1 for scenario 1 with TTP of 8.1s; where the *LMax* is 17 for East-West($V_{E\leftrightarrow W}$) bound. In the conventional method only 7 vehicles (8.1x7= 56.7s) can pass per lane in 60s and remaining 10 vehicles will be in queue, waiting for their turn until the next iteration. While OTSAT assigns GLT of 137.7s (17 × 8.1) for the same iteration with No queue for East-West ($V_{E\leftrightarrow W}$). Likewise for scenario 2 with TTP of 4.5 s, for the conventional method, there will be a queue of 4 cell-phones/Vehicles (since only 13 vehicles can pass during 60s), while there is no queue for the proposed method. Finally for scenario 3 with TTP of 6:0s, there will be queue of 7 cell-phones/Vehicles (since only 10 vehicles can pass during 60s) for conventional method, whereas there is no queue for OTSAT and likewise remaining iterations have been calculated. In Fig. 8(b) shows the iteration #1 for scenario 1 with TTP of 8.1s; where the *LMax* is 14 for North-South ($V_{N\leftrightarrow S}$) bound, 7 vehicles will be in queue, while OTSAT calculates GLT of 84s for same iteration. Likewise for scenario 2 with TTP of 4.5 s, there is no vehicle at all on roadways for North-South ($V_{N\leftrightarrow S}$) bound to cross but signal light will still be green for 60s and finally for Scenario 3 with TTP 6.0 s, there will be a queue of 4 cell-phones/Vehicles for conventional method, whereas there is no queue for OTSAT and likewise remaining iterations have been calculated. At the end of each traffic light iteration, vehicles those could not pass the intersection contributes to the formation of a queue for the next iteration in conventional method. However for OTSAT, the queuing is reduced drastically.

Considering the results for moderate traffic type in Fig. 8, we can show an average numbers of cell-phones/Vehicles remained in queue per iteration for East-West($V_{E\leftrightarrow W}$) and North-South ($V_{N\leftrightarrow S}$) bound in Fig. 9. For Scenario 1, there is an average of 22/9 cell-phones/Vehicles for East-west ($V_{E\leftrightarrow W}$) and 23/10 for North-South ($V_{N\leftrightarrow S}$) bound remained in queue. For Scenario 2, there is an average of 16/1 cell-phones/Vehicles for East-west ($V_{E\leftrightarrow W}$) and 0/0 cell-phones/Vehicles for North-South ($V_{N\leftrightarrow S}$) bound and likewise for Scenario 3, there is an average of 19/5 cell-phones/Vehicles for East-West ($V_{E\leftrightarrow W}$) and 20/6 North-South ($V_{N\leftrightarrow S}$)bound remained in queue for the conventional method versus OTSAT.

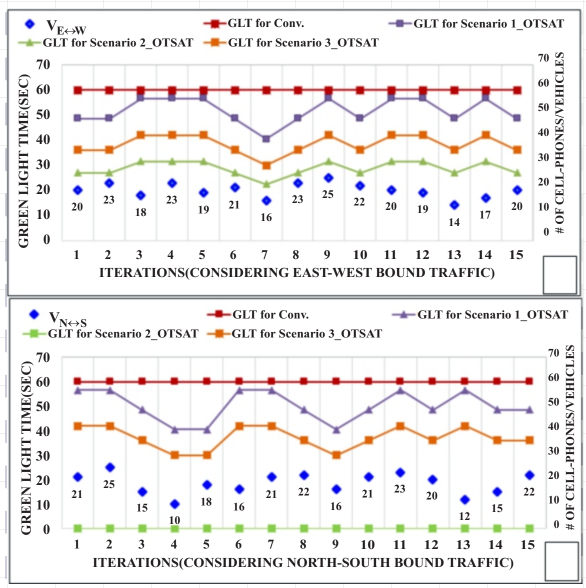

Fig. 8. Queue length of Conventional and OTSATfor moderate traffic a) East-Westand b) North-South bound

Considering the results in (Fig. 9 and10), an average queue of 668, 234 and 578 cell-phones/Vehicles for conventional method and 278, 10 and 155 cell-phones/Vehicles for OTSAT, for both East-West($V_{E\leftrightarrow W}$) and North-South ($V_{N\leftrightarrow S}$) traffic for 30 iterations, proofs that, OTSAT provides a significant reduction of queuing at an average of 77%, consequently would cause an equivalent idling time in queue for the East-West ($V_{E\leftrightarrow W}$) and North-South ($V_{N\leftrightarrow S}$) bound. According to the Air Quality Development Authority, the average vehicles consume about 0.156 gallons of fuel per hour while idling and emits 19.6 pounds of CO2 for each gallon of fuel it burns .OTSAT reflects a reduction of 77% of fuel wasted and CO_2 emissions compared to the conventional method (Fig. 10 and 11).

One may argue here that green light time for the conventional method may be fixed to 120 s or 180 s, instead of only 60 s to eradicate the bottleneck effect. Refer Table I, where we have calculated the efficiencies for 60 s, 120 s, and 180 s for Light, Medium and Heavy traffic for Scenario 1,2 and 3 for conventional method and OTSAT and found that still our method offers queue reduction efficiency on an average of 100% for "Light", 57% for "Medium" and 52% for "Heavy" traffic over conventional method. It also reveals that even under "heavy traffic", the proposed algorithm has the potential to attain the queuing reduction efficiency, on an average from 22% to 100% for scenarios 1 and 2.

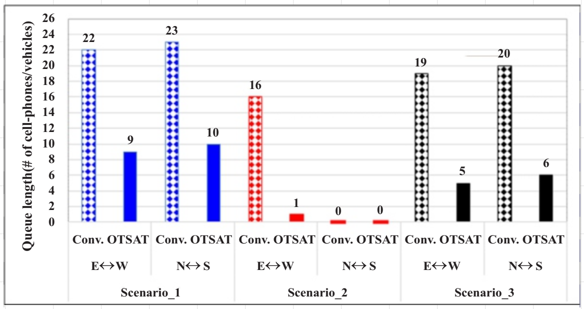

Fig. 9. An average Queue for East-West and North-South for moderate traffic

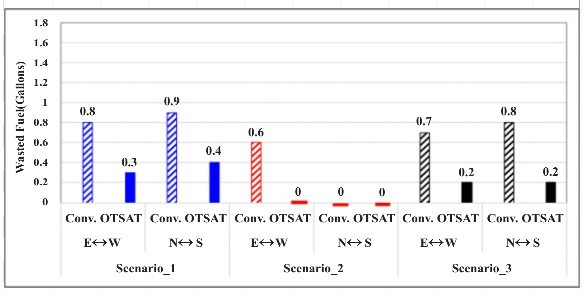

Fig. 10. Wasted fuel (gallons) for East-West and North-South bound traffic

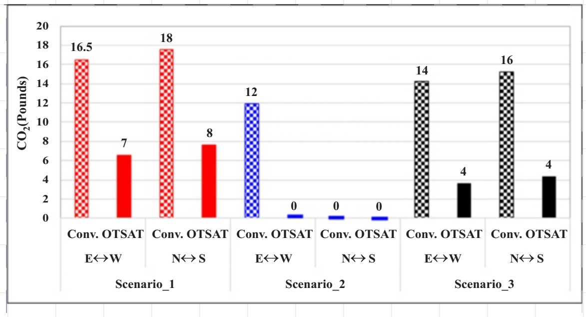

Fig. 11. Emitted CO_2 (pounds) for East-West and North-South bound traffic

TABLE I

Traffic Type	Scenario	Conv. Method GLT=60 Sec (%)	Conv. Method GLT=120 Sec (%)	Conv. Method GLT=180 Sec (%)	Average (%)
Light	1	100	100	100	100
	2	100	100	100	100
	3	100	100	100	100
Medium	1	58	35	0	31
	2	100	100	100	100
	3	73	51	0	41
Heavy	1	42	25	0	22
	2	100	100	100	100
	3	51	43	0	35

In the United States, the average commute time per commuter is 27.2 minutes [xxiv], which includes an average of 5 minutes waiting in front of traffic lights for each commute which means an average of 42 hours each commuter waste per year [xxv]. On the other hand, using our proposed OTSAT method, an individual commuter will not only avoid the time unnecessarily waiting on traffic lights but also fuel consumption and Pollution (CO_2) will drop significantly.

V. Conclusion

This paper proposes a solution for controlling traffic lights at intersections by exploiting the knowledge of location and Direction of Arrival from Smart Antenna used in the existing mobile communication systems. We presented system modeling and the analysis for different scenarios. From the extensive analysis performed, we observed that the proposed system has the potential to attain the queuing reduction efficiency from 22% to 100% with respect to traffic scenarios with different traffic patterns under consideration in this study. Consequently, such an approach reduces fuel consumption and CO_2 in the same ratios by avoiding queue and congestion (idling) on traffic lights.

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