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Reducing Traffic and Pollution in Cities Using Optimal Vehicular Network Routing Algorithms

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Abstract: There is a great requirement to reduce air pollution and transportation delay in cities roads. This paper presents a new routing algorithm, Optimal Traffic and Pollution Control Routing algorithm (OTPCR), based on the mathematical modeling and Infrastructure communication (V2I) strategy to minimize vehicle traveling delay and air pollution in city roads. Our new routing algorithm (OTPCR) at first will construct a mathematical model which formulate: vehicles traffic, roads topology and air pollution parameters and next it solves the obtained mathematical model in order to compute and find the best path (π) between source and destination for traveling vehicle. The Mathematical model which is called Vehicular Network Linear Programming Model (VLPM) is based on the Linear Integer Programming Formulation (LIPF) and Simplex optimization rules. Note that the best path is an optimal path and can minimize air pollution in city roads and transportation delay of vehicles. V2I communication strategy uses a Mobile Ad Hoc Networks (MANET) system to transfer vehicle traffic information. Our simulation results show that our new algorithm is more efficient than other available routing algorithms. Time complexity of our algorithm is acceptable and can reduce message distribution across the network.

Key words: VANET, linear programming, routing, air pollution, traffic delay reduction

INTRODUCTION

Today's environmental management is one of important challenges in world cities. It is clear that vehicular navigators based on real-time traffic conditions achieve suboptimal results since, in face of vehicle congestion, they greedily shift drivers to currently light-traffic roads and cause new traffic jams (Fig. 1). Now a days, heavy vehicular traffic threats light traffic and fresh air in cities which is one of very important challenges in urban environmental management (Xia *et al.*, 2015; Sanchez *et al.*, 2014; Zadeh *et al.*, 2010).

Concepts and definitions: Certainly if there is anything that affects almost government expenditure and everyone living in urban areas, regardless of income or social class, it is vehicular traffic congestion (Xia *et al.*, 2015; Sanchez *et al.*, 2014; Zadeh *et al.*, 2010). Besides the lost time and productivity, traffic congestion also exacerbates pollution and greenhouse gas emissions. In this study, we will present a new routing algorithm for reducing transportation delay and pollution in roads of city based on the vehicles traffic to infrastructure communication which uses mobile ad hoc networks and optimization theory. Figure 2 shows a classification of routing protocols in vehicular networks. Our new algorithm, Optimal Traffic and Pollution Control Routing algorithm (OTPCR), studies and models three following components:

Air pollution in city roads: Air pollution is the introduction of particulates, biological molecules, or other harmful materials into city's atmosphere, causing diseases, death to humans, damage to other living organisms such as animals and food crops, or the natural or built environment. Air pollution consists of particles NO, NO_2, SO2, CO, O_3, THC, PM, DUST, particulate matter PM_{10}, fine particulate matter ($PM_{2.5}$) which are declared in term μ gram m^{-3}. The Pollutant Standards Index (PSI), is a type of air quality index, which is a number used to indicate the level of pollutants in air. Pollutant Standards Index (PSI) can vary between min = 0 (good value) and max = 400 (dangerous value). The following PSI table, Figure 3, is grouped by index values and descriptors, explaining the effects of the levels, according to International Environment Agency.

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Fig. 1: Pollution and transportation delay is one of the major and important challenges in cities and environmental management. There is a great international requirement for reducing air pollution and transportation delay in industrial cities

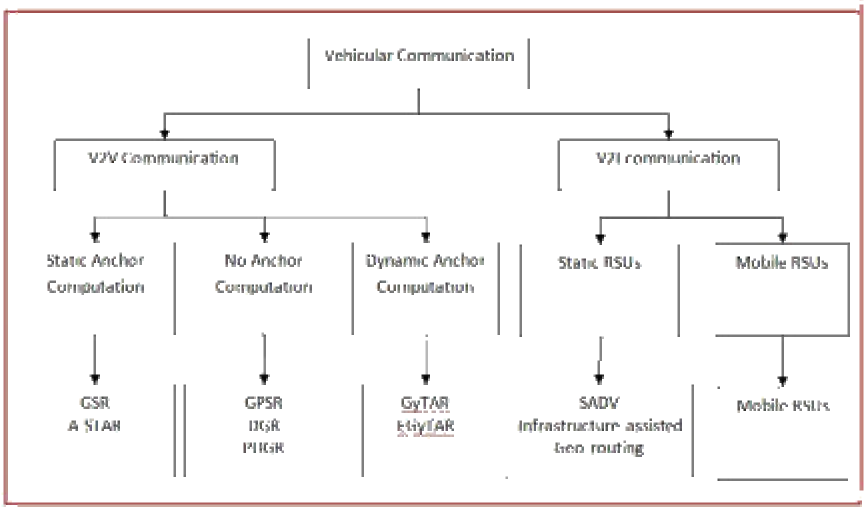
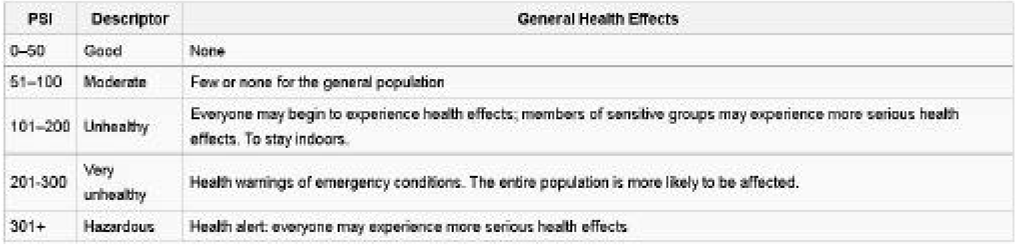


Fig. 2: Classification of routing protocols (solutions) in vehicular networks (Saleh *et al*., 2004; Baraa *et al*., 2015; Biswas and Singh, 2004)



PSI	Descriptor	General Health Effects
0–50	Good	None
51–100	Moderate	Few or none for the general population
101–200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects. To stay indoors.
201-300	Very unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.
301+	Hazardous	Health alert: everyone may experience more serious health effects

Fig. 3: International index grouped air pollution values (Biswas and Singh, 2014; Hana *et al*., 2010)

Transportation delay: Both traffic congestion and transportation delay are characterized by slower speeds, longer trip times, high fuel consumption, and increased queuing. They are the indicators of traffic demand that is greater than the available capacity of the road network. These conditions are exacerbated by both undesirable decisions and cultural a airs that do not promote the most efficient use of the transportation network.

Road topology: In the last decade, topological analysis has been widely adopted to uncover patterns or structures from various real world systems including information, social, environmental, technology and biological. In this study, for roads of a segment of the city we will derive a topological pattern of urban street networks using graph theory rules and some new notations. We will use this graph of roads to compute the

Fig. 4: Showing roads, intersections and roundabouts in a city using a topological graph in order to achieve mathematical modeling and path computation

light traffic-pollution paths. It is found that all the topologies of urban street networks based on street-street intersection demonstrate a small world structure, and a scale-free property for both street length and connectivity degree. Figure 4 shows a sample of city roads topology.

MATERIALS AND METHODS

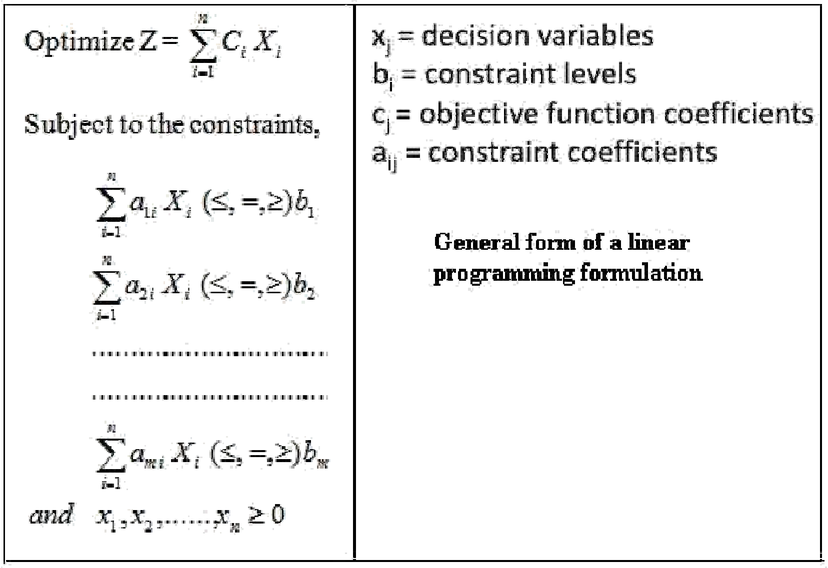
Mathematical Modeling for Optimal Computation Routing: A lot of problems such as vehicle traffic routing, traffic management and transportation costs, can be formulated as linear programs, and there exist efficient methods such as Simplex rules to solve them or at least give good approximations (Isazadeh and Heydarian, 2008; Isazadeh and Heydarian, 2010; Zhu and Ukkusuri, 2015; Isazadeh and Heydarian, 2012; Heydarian, 2012; Florin and Olariu, 2015; Heydarian and Mogavi, 2013; Heydarian, 2013; Heydarian, 2016). Moreover, there exists methods for routing and load balancing of networks (Mirrezaei *et al*., 2007; Mirrezaei *et al*., 2009) based upon the topology of their underlying networks. In this study our new algorithm at first transforms city roads map to a graphical topology which weights of edges are properties of roads and vehicles traffic. After that we will construct and Linear Integer Programming Formulation (LIPF) based on the obtained topology to minimize objective function which formulates air pollution and transportation delay of vehicles between source and destination. By solving the obtained LIPF the best path which has minimum delay and air pollution is selected to travel. The new algorithm can use light pollution-traffic paths however length of path increased. Therefore, we claim that our new algorithm can distribute vehicle traffic and decrease air pollution. Figure 5 shows the general form of a Linear Integer Programming Formulation (LIPF) which consists of coefficients and variables x_i, b_i, c_i, and a_{ij}.

Requirements of VANET: A VANET is a heterogeneous wireless network that forms among the vehicles on the basis of need (Hoeft and Rak, 2016; Bian *et al*., 2016; Baraa *et al*., 2015). Every vehicle must have wireless transceivers and computerized control modules that allow the vehicle to act as network nodes and then only these vehicles can participate in a VANET environment.

The wireless network range of every vehicle may be limited to a few hundred meters, thus source to destination communication across a larger distance need messages to hop through several nodes. This requires a real time transmission of message from source to destination. Although VANET environment does not require any fixed infrastructure, but fixed network nodes may be used in the form of Road Side Unit (RSU) (Atallah *et al*., 2015; Saleh *et al*., 2014; Li *et al*., 2015). These RSUs help in a number of ways to provide various services for vehicular networks, like relaying the messages on sparse network, working as gateway to connect to the Internet.

In this study we suppose that there are wireless transceivers, computerized control modules, RSU, central routing computer (link state based) and communication between vehicles and central routing computer. Central routing computer runs our new algorithm and computes the best path and vehicles will use it. A vehicular network contains Vehicular Nodes (VN), vehicles equipped with On Board Units (OBU), and fixed node called Road Side Units (RSU). These RSUs are connected to infrastructure network that will be available for every vehicle and fixed on road side. OBU and RSU can communicate with the vehicles using wireless (ad hoc) techniques.

Some available traffic management algorithms: Now we study some available routing algorithm in VANET in order to specify their advantages and weaknesses.



Optimize $Z=\sum_{i=1}^{n} C_i X_i$

Subject to the constraints,

$$\sum_{i=1}^{n} a_{1i} X_i \ (\leq,=,\geq) b_1$$

$$\sum_{i=1}^{n} a_{2i} X_i \ (\leq,=,\geq) b_2$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\sum_{i=1}^{n} a_{mi} X_i \ (\leq,=,\geq) b_m$$

$and \quad x_1, x_2, \ldots\ldots, x_n \geq 0$

x_j = decision variables

b_i = constraint levels

c_j = objective function coefficients

a_{ij} = constraint coefficients

General form of a linear programming formulation

Fig. 5: A general form of a linear integer programming formulation consisting of con-straints, decision variables, constraint level coefficients, objective function coefficients and constraint coefficients

Positioned based routing algorithms: In Position Based Routing Protocol, nodes in vehicular networks mostly depend on the information of position in order to make decisions about routing. Therefore, the information about the location obtained from street maps and traffic models make this type of routing protocol better than the ad hoc based routing protocol. A position-based routing protocol has many key mechanisms such as beaconing, location service, location server, forwarding strategy and recovery strategy. Depending on the requirement, the use of some of these components are optional in certain position based routing protocols.

One of the main advantages of using position based routing is that it's characteristic does not requiring maintenance of routes, which is very suitable for highly mobile networks such as the VANET environment (Xia *et al*., 2015; Bilal *et al*., 2013). The routing path is determined at the time when packets are required to be forwarded. Only the position of the destination as well as other information such as the node identifiers, forwarding nodes and their neighbor positions are required in order to forward information or packets from the source to the destination.

The main requirement to make safer journey in VANET environment is minimum delay with high packet delivery rate. This ensures that all data packets are received with minimal delay to prevent any accident. presents a new algorithm for VANET class routing protocol that covers sparse and coarse region of vehicles. It takes the advantage of road layout to improve the performance of routing in VANETs. (Saleh *et al*., 2014; Zhu and Ukkusuri, 2015) uses real-time GPS tracking system to obtain traffic information for creating road based paths from source node to destination node. The optimize forwarding is used to figure out the forwarding node along the road pattern that form the path to deliver the data packets.

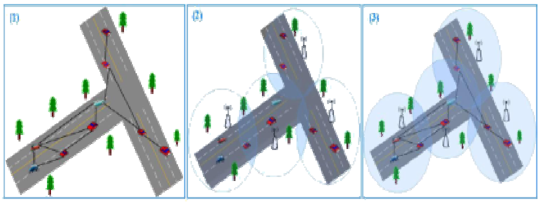
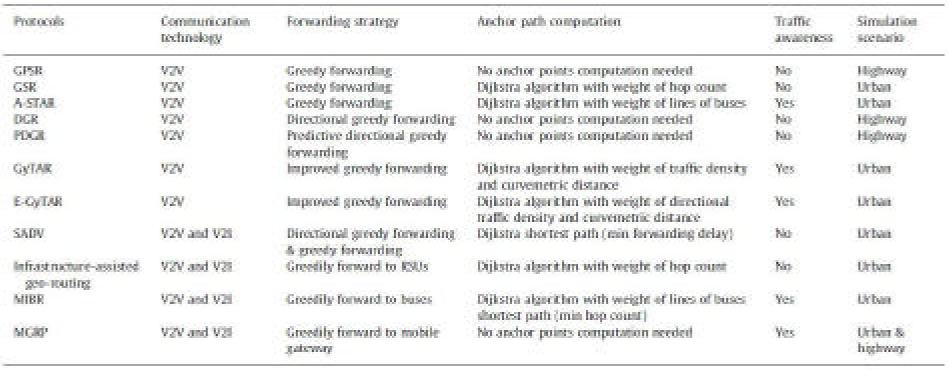


Fig. 6: (1) Pure ad hoc network; (2) Pure cellular/WLAN; (3) Hybrid architecture or position based algorithm. These three types of networks suffer from some weaknesses (Baraa *et al*., 2015)

The proposed routing algorithm (VTARA) discussed in differs from these protocols in which the routes are created on the basis of road topology. The primary segments of routes are intersection point at junctions that lie along the path from the source to the destination. The node positions are used to route data between endpoints in Geographical routing protocols. In these protocols, a source computes the shortest road based path from its current position to the destination.

As shown in Fig. 6, usually position based routing algorithms suffers from some weaknesses:



Protocols	Communication technology	Forwarding strategy	Anchor path computation	Traffic awareness	Simulation scenario
GPSR	V2V	Greedy forwarding	No anchor points computation needed	No	Highway
GSR	V2V	Greedy forwarding	Dijkstra algorithm with weight of hop count	No	Urban
A-STAR	V2V	Greedy forwarding	Dijkstra algorithm with weight of lines of buses	Yes	Urban
DGR	V2V	Directional greedy forwarding	No anchor points computation needed	No	Highway
PDGR	V2V	Predictive directional greedy forwarding	No anchor points computation needed	No	Highway
GyTAR	V2V	Improved greedy forwarding	Dijkstra algorithm with weight of traffic density and curvemetric distance	Yes	Urban
E-GyTAR	V2V	Improved greedy forwarding	Dijkstra algorithm with weight of directional traffic density and curvemetric distance	Yes	Urban
SADV	V2V and V2I	Directional greedy forwarding & greedy forwarding	Dijkstra shortest path (min forwarding delay)	No	Urban
Infrastructure-assisted geo-routing	V2V and V2I	Greedily forward to RSUs	Dijkstra algorithm with weight of hop count	No	Urban
MIBR	V2V and V2I	Greedily forward to buses	Dijkstra algorithm with weight of lines of buses shortest path (min hop count)	Yes	Urban
MGRP	V2V and V2I	Greedily forward to mobile gateway	No anchor points computation needed	Yes	Urban & highway

Fig. 7: Comparison of routing protocols in V2I and V2V communication routing algorithms (Saleh *et al*., 2014; Baraa *et al*., 2015)

- They act locally and cannot route globally
- They inherit routing information protocols and shortest path routing properties
- Handover latency reduces their efficiency
- And also they are not multi parameter routing algorithms

Another routing algorithm which is categorized in MANET classification is Ad Hoc on Demand Distance Vector (AODV) which inherits weaknesses of MANET (Mohapatra and Kanungo, 2012; Bitam, 2013).

Shortest path based routing algorithms: MIBR is a position-based reactive routing protocol in which buses are used as an essential factor during route selection and data transfer. Figure 7 shows a Comparison of routing protocols in Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) communication (Florin and Olariu, 2015; Liu *et al*., 2016; Fonseca and Vazao, 2013; Gaddour *et al*., 2015).

Figure 7 shows that many VANET routing algorithms are based on the MANET and Dijkstra algorithm and we will compare our new algorithm with these two general types of VANET.

Some terminologies and notations: Before presenting our new algorithm, we must define some new terminologies and notations. Suppose that the number of vehicle in a road which is counted by a RSU station is shown by Number of Vehicle (NoV). For studding our problem, we suppose that all roads, intersections and roundabouts of the city are modeled by a graph G (V, E) which set of V (vertexes) shows all both intersections of crossing roads and circular intersections (roundabouts). A roundabout is a type of circular intersection or junction in which road traffic flows almost continuously in one direction around a central island. Also set of E (edges) shows all available roads which each of them connect two vertexes of the V. Each road (edge) is labeled with an index i. Each edge e_i of E is tagged by a quaternary numbers (L_i, AB_i, P_i, d_i) which L shows length of the road (meter), AB shows the Available Bandwidth (capacity), P shows the air pollution ($0 <= P <= 20$) and d is transportation delay (second) of that road. Available Band width (AB) of a road shows the maximum number of cars that can be located across the road in the manner that cars can move by a constant velocity. We propose the following heuristic formulation for computing AB:

$$AB = \frac{\text{lanes} \times L}{\left\lfloor \frac{\text{Velocity}}{k} \right\rfloor \times \text{distance}} - \text{NoV}$$

In this formula we have:

- Lanes: The number of lain lines in a road in which cars traffic flows almost continuously (Wide of a road is divided to some lanes)
- Velocity: Maximum speed that all cars in the road cannot exceed it
- Distance: A space which each car must keeps aloof from ahead car
- k: A constant number. Formula shows that if k increases (AB grows) then the road will be congested and vice versa. k cannot exceed Velocity. Velocity, k, and distance are arbitrary values which can be set by OTPCR algorithm. If we suppose that:

$$\text{MAxB} = \frac{\text{lanes} \times L}{\left\lfloor \frac{\text{Velocity}}{k} \right\rfloor \times \text{distance}}$$

Above formula proves that current traffic of vehicles (NoV) cannot exceed Max B. Figure 8 shows that a sample graph can model roads of vehicle traffic in the city.

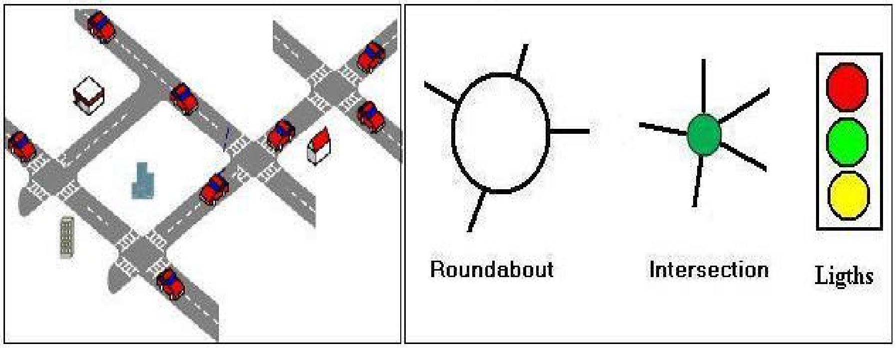


Fig. 8: A sample graph showing some rods and some intersection and roundabouts. Traffic Lights (green, red and yellow) or traffic signals control conflicting flows of car traffic and prevent car accidents and schedule queuing of vehicles

Informal definition of the problem: Suppose that there are some rods consisting of intersections and roundabouts which vehicles go along them. Each vehicle starts it's travel from a source point and comes to a destination point. Informally, for each vehicle we must compute an optimal path ð between source and destination points which minimizes air pollution and total time of travel along the path π.

Formal Definition of the Problem: Suppose that graph G(V,E) models all roads in our city area that it's traffic must be con-trolled optimality and desirably. Also, suppose that Air Pollution, length of roads and transportation delay along each road are given. Now compute optimal path in order to travel a vehicle from a source point to a destination point which air pollution, traffic queuing and time duration of travel be minimized. All conditions, variables and known values must be formulated as a solvable mathematical problem. By solving this mathematical problem, the optimal paths must be achieved as an optimal solution. Also mathematical problem must be feasible and must have at least one optimal solution. Mathematical problem must change and manage the known values dynamically and synchronously.

We claim that this mathematical problem and its optimal solutions can be constructed using Linear Integer Programming Formulation (LIPF). In the next section we will construct and present this mathematical problem and its solution. We solve it using Simplex method for achieving the all available and feasible optimal solutions.

New algorithm: optimal traffic and pollution control routing algorithm (OTPCR-VLPM): As mentioned before, for constructing and presenting our new algorithm (OTPCR), we use Linear Integer Programming formulation (VLPM) which can formulate air pollution and transportation delay. Now we must determine conditions (constraints), and decision variables, and all coefficients of VLPM and also we must determine all steps of OTPCR algorithm.

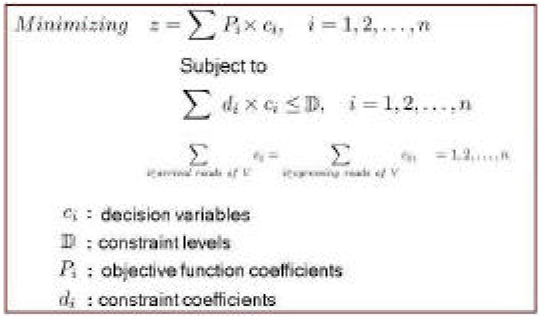
The New Vehicular Linear Programming Model (VLPM): Suppose that a vehicle wants to travel from the source point A to the destination point B which are connected with path π which consists of some consecutive continues roads, and some signal lights. VLPM be presented as the following objective function:

$$\text{Minimizing } z = \sum P_i \times c_i, \; i = 1, 2, \ldots, n$$

In this objective function n is the number of roads and each road is tagged by index i. The coefficient Pi is the value of pollution in each road i = 1, 2,…, n. Variable ci is a binary decision variable which can take on only two possible values 0 and 1. If c = 0, the vehicle does not pass road i because road i does not belong to path π. ci = 1 means that road i belongs to path and the vehicle can pass road i. This objective function minimize sum of pollutions along path π. Therefore, the objective function complies and provides pollution constraints. Transportation delay constraint:

$$\sum d_i \times c_i \le D, i = 1, 2, \ldots, n$$

In this constraint, n is the number of roads and delay of each road is indexed by d_i. d_i shows propagation delay of road i. In the other words, a vehicle can pass road i during d_i time units in term of second or minute. This constraint uses parameter ID to control (increase or decrease) the transportation delay of path π. By increasing ID, we can elongate path π. In the other words, by decreasing ID, path must become smaller in length.



$Minimizing \quad z = \sum P_i \times c_i, \quad i = 1, 2, \ldots, n$

Subject to

$\sum d_i \times c_i \leq \mathbb{D}, \quad i = 1, 2, \ldots, n$

$\sum_{i \in \text{arrival roads of } V} c_i = \sum_{i \in \text{egressing roads of } V} c_i \quad = 1, 2, \ldots, n$

c_i : decision variables

$\mathbb{D}$: constraint levels

P_i : objective function coefficients

d_i : constraint coefficients

Fig. 9: Illustrates the general form of VLPM including all coefficients and variables

Directional constraints: In each intersection or roundabout, the number of vehicles that leave input roads, must be equal to the number of vehicles which arrive in egressing roads (the number of both input and output vehicles is the same).

As mentioned before, we suppose that there is a central computer that computes an optimal path π for each vehicle. This means that each vehicle does not have a private VLPM software and does not run it's VLPM itself. Therefore, for each vehicle central computer must have the following private directional constraints:

$$\sum_{i \in \text{arriual roods of V}} c_i = \sum_{i \in \text{arriual roods of V}} c_i \quad = 1, 2, \ldots, n$$

Directional constraints for each vehicle are global constraints which may differ from a vehicle to another vehicle. These constraints are dependent on source, destination, and traffic loaded on the roads that connect source to destination. This means that coefficients of VLPM may vary from a vehicle to another vehicle however the general form of VLPM is constant. Figure 9 a general form of a linear integer programming formulation VLPM consisting of constraints, decision variables, constraint level coefficients, objective function coefficients and constraint coefficients.

As will mentioned in Section 2.3, we know that AB< = MaxB and NoV< = MaxB (MaxB = AB + NoV). Suppose that In_i shows the number of all arrival vehicles in road i per minute (input rate of vehicle) and also Out_i shows the number of all going out vehicles from road i. In this case it is clear that NoV in road i will be equal to:

$$NoVi^{new} = NoVi^{old} + (In_i - Out_i) \times \Delta t + \Psi_i \geq = 0$$

Ψ_i is the number of vehicles that are added locally in intersection i. This equation shows that arrival vehicles may be accumulated in road i. In this study for all simulations, the value of Δt is equal to duration of green light in an intersection and can be considered in term of second or minute. Suppose that duration of green light is 40 second. In this case finishing and completing each green light (40 second) increases Δt by one: Δt = Δt + 1. In the start of simulation, Δt is initiated at zero and after that we will have Δt = 1, 2, … 8. In each Δt we can construct VLPM and we denote this by VLPM(Δt). Also in each road i for each arrival vehicle we can compute value of delay as the following:

$$d_i = D_i + \frac{NoV_i}{Out_i}$$

This means that if a new vehicle arrives in rode i it can goes out after d_i time unites (second or minute). If NoV_i = 0, D_i is some needed time units (seconds or minutes) that takes long until the arrival vehicle passes the road i:

$$Di = \sum_{L_i \in \pi} \frac{L_i}{Velocity} + \sum \left(\text{duration of Red Light}_i \in \pi \right)$$

Steps of the new algorithm OTPCR: Steps of OTPCR will show that how Ät and V LPM(Ät) will be initiated and computed. Also OTPCR computes optimal path for each vehicle and manages vehicular traffic. Suppose that a vehicle | wants to travel from source A to destination B. Steps of OTPCR are as the following:

- Step-1: Construct the vehicular network topology G(V; E) of roads and suppose that the number of roads is n. Initiate Δt = 0, $In_i = Out_i = 0$, i = 1, 2, …, n, and compute L_i and D_i. This means that there is no traffic in the city in initiation state
- Step-2: Let Δt = Δt + 1 and for each road i two parameters ${}_i$ and In_{Source} take values randomly. In_{Source} is the number of vehicles that source node S loads to the networks
- Step-3: For each road i compute and specify D_i, d_i, P_i, and input D from driver. Now, construct VLPM (Δt).
- Step-4: Solve VLPM (Δt) and compute value of all variables c_i for each road i
- Step-5: For each vehicle K using obtained variables c_i, specify optimal path π j =< c_{j1}, c_{j2}, …, c_{js} > which c_{jk} = 1, k = 1, 2, …, s. Length of path π_j is $L_{\eth j} = c_{jk} L_{jk}$. Note that L_{jk} = length of road j_k
- Step-6: Suppose that two roads c_{jk} = (X; Y) and c_{jk+1} = (Y; Z) which belong to π_j, are located sequentially and connect three intersections X, Y and Z. Now using Traffic Shaping Algorithm (TSA, Section 3.3) update:

$$\mathrm{NoV}_{(X,\,Y)} = \mathrm{NoV}_{(X,Y)} - \mathrm{Out}_{(X,Y)} + \mathrm{In}_{(X,Y)} + \Psi_{(X,Y)}$$
$$\mathrm{NoV}_{(Y,\,Z)} = \mathrm{NoV}_{(Y,\,Z)} - \mathrm{Out}_{(Y,Z)} + \mathrm{In}_{(Y,Z)} + \Psi_{(Y,Z)}$$

and $\mathrm{Out}_{(X,Y)} = \mathrm{In}_{(Y,Z)}$. This means that each vehicle K which goes out from (X, Y) and arrives in (Y, Z), it increases $\mathrm{NoV}_{(Y,Z)}$ by one.

- Step-6: Communicate path π_j to driver. Vehicle K must continue to its journey and must travel along path π_j
- Step-7: Count the number of delivered vehicles to destinations and if there are vehicle in the network topology go to Step-2 else STOP

Traffic Shaping Algorithm (TSA): Step 6 of OTPCR shapes and manages traffic of vehicles in the intersections of vehicle net-work. In fact OTPCR connects ingress roads to egress roads in intersections ans switches vehicles. Step 6 of OTPCR does not vary duration of green or red lights in intersections. For completing Step 6, we present Traffic Shaping Algorithm (TSA) as the following (Note: False red and True green):

- Boolean LIGHT=False;
- if LIGHT=red, LIGHT = green, else {update NoV_i, Δt , AB_i, Ψ_i, D_i, d_i, P_i LIGHT = red;}

TSA algorithm changes the state of traffic signal and update traffic properties in each inter-section.

RESULTS AND DISCUSSION

Simulation results and computations comparisons: In this section we will apply OTPCR and some available vehicular routing algorithms to some vehicle sample networks in order to compare results. Simulation results will show that OTPCR is more efficient than other available algorithms.

Sample 1: reducing pollution and controlling transportation delay: Figure 10 shows a vehicular sample network consisting of one source, one destination, 5 intersections (green nodes), one round about and 9 roads. Consider that vehicles want to travel from source to destination and drivers must travel a path between them. For each road i a triple label (L_i, P_i, D_i) has been tagged. According to the size of vehicles and local congestion in each intersection, without any loss of generality for each road i we can suppose that values of In_i and Out_i are randomly selected as: $(10 <= \mathrm{In}_i, \mathrm{Out}_{i <=} 25)$ and next value of NoV_i will be computed based of them.

This means that during a green light, passing a vehicle across an intersection takes at least 40/10 = 4 and at most 40/25 = 1.6 seconds and vehicles are switched one by one consequently without any gap time between two sequenced vehicles (if duration of a green light be 40 second then duration of each red light will be 40 second).

We agree that value of $\Delta t = 1, 2, 3; \ldots$ is an integer number and will be increased one unit after finishing each green light. We suppose that across the simulation, in lieu of a number of Δt , red light, green light and yellow right are respectively:40 second, 40 sec and 4 second. In this study (research) we suppose that the duration of lights is selected arbitrarily (40 seconds) but in one of future works OTPCR will compute it optimally.

In Figure 10 we see that total pollution of path $\pi_1 = < 1, 8, 7 >$ is the biggest among total pollutions of paths π_1, π_2

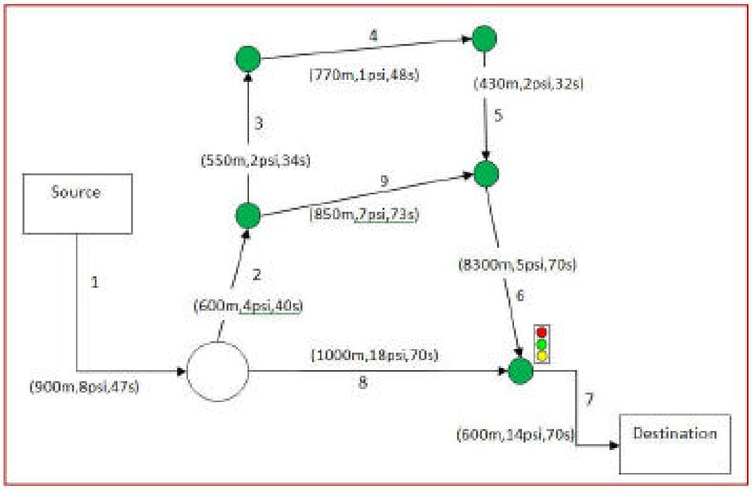


Fig. 10: A vehicular sample network consisting of source, destination, 5 intersections (green nodes), one roundabout, and 9 roads

Table 1: Shows that OTPCR as compared to Dijkstra, distributes traffic, decreases air pollution (%17), decreases delay (%21) and the number of Δt

Algorithm	Delivered	Di	Total PSI	π3	π2	π1	Δt
OTPCR	1000	3317z	3.1807	417	348	235	83
Dijkstra	1000	4189s	3.8066	231	310	459	105

= < 1, 2, 9, 6, 7 > and π_3 =< 1, 2, 3, 4, 5, 6, 7 > but its transportation delay is the least. By applying OTPCR to Fig 10, VLPM produces the following LIPF:

$$\text{Minimize } (8c_1+4c_2+2c_3+c_4+2c_5+5c_6+14c_7+18c_8+7c_9) \text{ s.t.}$$

$$47c_1+40c_2+34c_3+48c_4+32c_5+70c_6+70c_7+70c_8+73c_9 < D$$

$$c_1 = c_2 + c_8$$

$$c_2 = c_3 + c_9 \; c_3 = c_4$$

$$c_4 = c_5$$

$$c_5 + c_9 = c_6 \; c_6 + c_8 = c7$$

$$c_1,\ldots, c_9 = 0 \text{ or } 1$$

We can see that total transportation delay of path $_{ð1}$ = < 1, 8, 7 >, $_{\pi2}$ = < 1, 2, 9, 6, 7 > and $_{ð3}$ = < 1, 2, 3, 4, 5, 6, 7 > are 187, 300, and 341 respectively. At first by considering Δt = 1, if we set D = 180, the above LIPF will be infeasible and no optimal solution is computed. If we set D = 250 the above LIPF will come feasible and the most polluted path < 1, 8, 7 > is computed because of delay of $_{ð1}$ <=250. If we increase D to 310 or 350 two paths < 1, 2, 9, 6, 7 > and < 1, 2, 3, 4, 5, 6, 7 > can be computed as optimal solutions. This shows that OTPCR controls air pollution and length of optimal path by varying D.

Routing algorithms such as Dijkstra, OSPF, RIP and AODV cannot control delay and air pollution optimally. By applying Dijkstra to Figure 10, for various values of d_i, at rs only path $_{\pi1}$ will be selected and pollution will be seriously increased in this path. After saturating path π_1 =< 1, 8, 7>, Dijkstra may select path $_{\pi2}$ and $_{\pi3}$.

Now suppose that OTPCR continues simulation (Δt > = 2) and 1000 vehicles must travel from source to destination. Certainly, these 1000 vehicle will increase air pollution and OTPCR must reduce congestion, transportation delay and air pollution. Suppose that each vehicle j randomly produces value of PSI as: $0 <= PSI_j <= 0.0002$ PSI/Second. After applying OTPCR and Dijkstra to Fig. 10 iteratively and sequentially, Table 1 is obtained as the following:

Table 2: Obtained results of two algorithms

Algorithm	Delivered	Di	Total PSI	Δt
OTPCR	5000	4160s	31.807	107
Dijkstra	5000	6080s	38.066	152

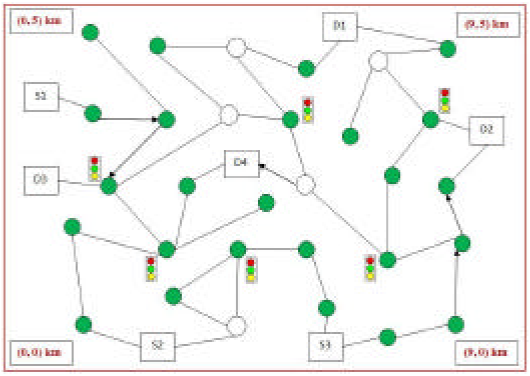


Fig. 11: A vehicular sample network consisting of 3 sources, 4 destinations, 30 intersections (green nodes) and roundabouts, and 41 roads

Sample 2: a large vehicular sample network: As shown in Fig. 11 the vehicular sample network consists of 3 sources, 4 destinations, 30 intersections (green nodes) and roundabouts and 41 roads. Length and wide of the vehicle network is 9 and 5 kilometers respectively. Each intersection or roundabout has a speciffic (x; y) coordinates. The length of road between two intersections is computed by euclidean norm.

We repeat all traffic conditions of Sample 1 for sample 2 and we suppose that 5000 vehicle must travel from one of sources to one of destinations randomly. An edge (road) is a bidirectional edge which consists of two contrary direction lanes. each lane is counted as a different and independent road. We suppose that there is a central routing computer which specially and separately runs OTPCR and VLPM for each vehicle traveling from a source to a destination. Because a vehicular network is not a real time network, they are not sensitive to delay, jitter, and computation time. Therefore, OTPCR and VLPM have long time to route all vehicle from their sources to destinations.

We apply tow algorithms OTPCR and Dijkstra to the sample network shown in Fig. 11. By starting simulation computations, Δt = 0 and there is no vehicle in the network. Vehicles will arrive at sources and after traveling the network, will be delivered to destinations.

Table 2 shows obtained results from applying two algorithms OTPCR and Dijkstra to sample network shown in Fig. 11 Figure 12 shows that the vehicle delivery rate of OTPCR is more stable than Dijkstra and it saves this rate high optimally. Delivery rate od Dijkstra is not optimally stable and falls suddenly. OTPCR delivers 5000 vehicles more quickly than Dijkstra and minimizes Δt.

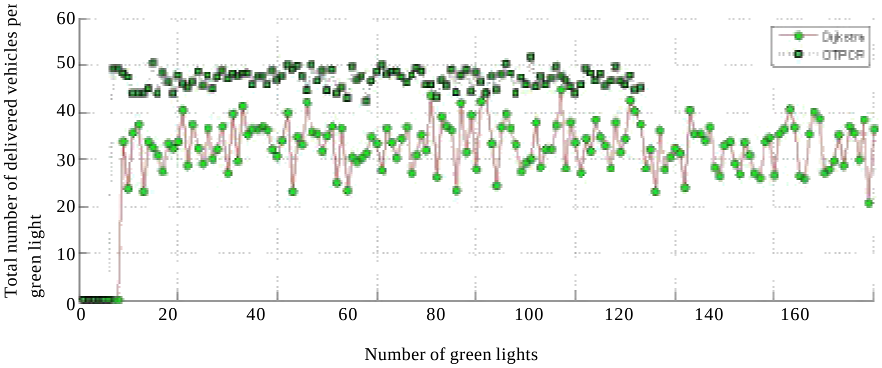


Fig. 12: Comparing traffic delivery: Total delivered vehicles to destinations per Δt . OTPCR delivers vehicles more quickly than dijkstra

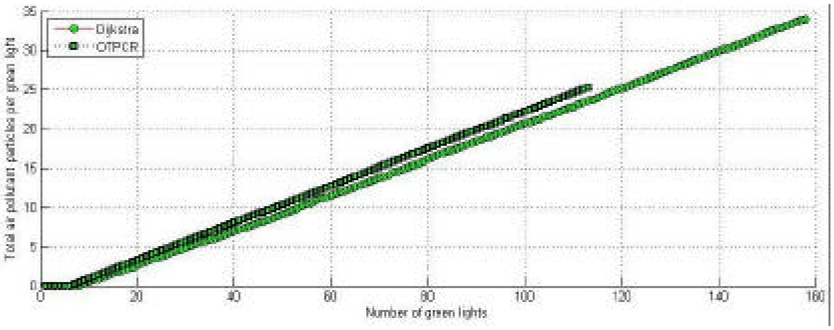


Fig. 13: Comparing generated pollution: Total generated pollution of roads per Δt

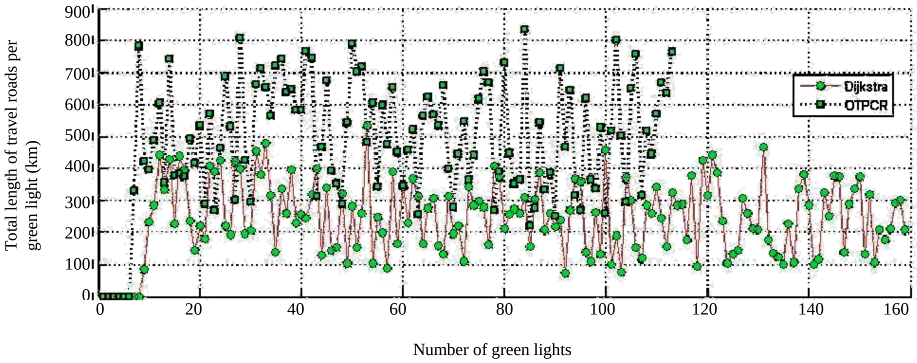


Fig. 14: Comparing total length of traveled roads per Δt

Figure 13 shows that OTPCR as compared to Dijkstra in the same Δt decreases total air pollutant particles which are generated by vehicles across passing the network. Figure 14 shows that OTPCR as compared to Dijkstra increases total length of traveled path π. In fact OTPCR minimizes air pollution and delay transportation however it may prolong the traveled paths. This means that OTPCR prolongs traveled paths in order to minimize air pollution and transportation delay. We must consider that not only the lengthy paths are not the main reason of high air pollution and delay, but also can reduce heavy traffic and congestion in the roads. Our new algorithm, OTPCR, can find congested paths and can decrease their heavy traffic using sending traffic in direction of empty or not crowded paths. This means that lengthy paths can reduce air pollution optimally.

For more enlarging the sample network shown in Figure 10, we can add new nodes, new intersections or new roundabouts to the figure until the number of roads and intersections be increased. By adding each road or intersection we must add equality to VLPM in order to obtain new VLPM. This means that if some roads be added to the network topology, there is no need to replace total VLPM. Instead of replacing VLPM we need only add some new constraints or update some of constraints in VLPM. By adding or updating constraints of previous VLPM, simulation of the new VLPM can be re-done. This a air means that VLPM has a great advantage as compared to another algorithm:

new V LPM = older V LPM+UPDATING
some constraints

Therefore, VLPM can be enlarged, updated and done rapidly.

CONCLUSION

In this study we has presented a new traffic routing algorithm for delivering vehicles in a vehicular network of a city in order to decrees air pollution and transportation delay. We have shown that our new algorithm is more efficient than other available routing algorithm in vehicular networks which use Dijkstra routing algorithm. Dijkstra is used by many routing algorithms in vehicular transportation networks.

SUGGESTION

Optimal computation of duration of signal lights: In this study, we saw that duration of red and green lights are not computed by OTPCR and VLPM optimally. We can change steps and constraints of OTPCR and VLPM in order to improve them to compute duration of lights optimally. This achieves new improved version of OTPCR and VLPM. OTPCR and VLPM cannot predict queuing or halting delay of a vehicle K when it arrives at a congested intersection. In fact intersections may be congested and arrival vehicles have to halt for an uncertain time. Traffic prediction can improve and reinforce OTPCR and VLPM to achieve better traffic management. We can add a machine learning algorithm to OTPCR and VLPM for achieving the better traffic management frameworks.

Reducing over load communication packets: OTPCR and VLPM use a central rout-ing computer to forward vehicles from sources to destinations which this centrality of computations can increase the number of information packets across the network. For removing the centrality problem We can suppose that each vehicle posses a special routing computer for running OTPCR and VLPM by itself. This means that route computations can be distributed on all vehicles. We can compare these two strategy: central routing and distributed routing for determining which strategy is more efficient and can reduce more desirably transportation delay and air pollution.

Multicast OTPCR: The current VLPM of OPTCR is a unicast routing algorithm and can only forward a vehicle along a path. This means that OTPCR cannot find a tree path for traveling a group of co-source vehicles (vehicles that stay in the same source but do not have the same destination). We can present a new version of VLPM for constructing a tree path. Certainly it can reduce the number of routing iteration and also can reduce employed roads.

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