Location Problem for Traffic Emission Monitors

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***Abstract*—In order to mitigate the air pollution caused by traffic, the monitoring of on-road vehicle emission is really an urgent issue. The Vehicle Emission Remote Sensing System (VERSS) is a promising technology to solve this problem. But there is scarcely any available location strategy for traffic emission monitors yet to our knowledge, which restraints the use of monitors on a large scale of traffic network. In this paper, we make some efforts to solve a novel location problem in the transportation domain, that is, we look for the minimum subset of roads on which traffic emission monitors should be located, thus we can detect as many on-road vehicles as possible. We explicate how to transform the location problem to some graph problems and give the problem formulation mathematically. Then a two-step algorithm is designed to find the set of roads to locate monitors. The simulation test verify its availability. And in the last section some problems that should be studied further are presented at the end of the paper.**

I. Introduction

With the rapid economic growth and urbanization development, numerous roads are being built to form an accessible and convenient transportation network. Over the last decades, a tremendous increase in vehicles arises to meet with the requirement of great traffic demand, but the vehicle exhaust pollution coming with it has contributed the majority of air pollutant in cites. The exhaust from vehicles contain carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide(NOx), particulate matter (PM) and many other toxic substances, increasing the occurrence possibility of atmospheric haze and photochemical smog, and then causing respiratory and cardiovascular diseases such as asthma, bronchitis, stenocardia and coronary heart disease. Since a majority of vehicles are usually driven in densely populated areas, the pollution caused by vehicles greatly endangers human life. As the environmental pollution problem has aroused more and more attention from the public, controlling the vehicle exhaust pollution increasingly highlights its importance.

It is remarkable that the *yellow-labelled cars* are most contaminating among all vehicles in terms of air pollution. It was reported in the 2014 annual report of the Ministry of Environmental Protection of China, that the yellow-labelled cars contributed 52.4% of NOx, 52.9% of HC, 49.0% of CO and 78.8% of PM in the whole emission pollution in 2013, despite their 10.7% share of all the vehicles [4]. In the same report, it was claimed that the 0.9% reduction of the whole emission pollution despite the 3.5% yearly increase of the vehicles, should be credited to the more rigid regulations on the yellow-labelled cars. Therefore, tools and analysis are urgently needed that can quantify the emission effects of these yellow-labeled cars, in order to assist the regulation design of the government.

The common detection methods for vehicle emission can be classified into four general categories, the non-load test (under conditions of idle speed and double idle speed), the driving mode test, the remote sensing monitoring and the portable emissions measurement system. Since off-line methods that measure the exhaust gas by simulating running states are unable to capture the real-time emission effectively, it is necessary to design a remote sensing system for emission detection, capable of detecting the emission of all vehicles when they are up and running. Such a system can be used for the automatic, real-time online monitoring, providing valuable information for vehicle emissions which can then be used for the government to design more pollution-aware policies.

The Vehicle Emission Remote Sensing System (VERSS) is a promising method to monitor vehicles and identify yellow-labelled cars. Such a system is implemented by locating traffic emission monitors on the road which forms a monitoring network. With non-contact optical emission detection devices distributed onto the urban road network, massive vehicles can be monitored in real time. Not surprisingly the amount and location of the monitors are key to the monitoring performance. Ideally the more devices the system has, the better performance we can expect. However any realistic system is constrained by the economic considerations. Therefore, the balance between the cost and the performance, and consequently the optimization of the location become one key technique in the remote sensing system. But few results have been available to date to the best of our knowledge.

In the existing literature on traffic sensor location problem, People focus on how to distribute the minimum number of traffic flow sensors on a road network such that the traffic flow on the entire network can be determined. Lam and Lo provided one of the first formal treatments of the problem

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with respect to traffic flow, by considering how to estimate origin-destination matrices from traffic counts [9]; Yang et al. analyzed the relationship between the quality of an estimated origin-destination matrix and the distribution of the sensors, resulting in a set of rules for optimizing locations [10]. Bianco et al. extended this problem by studying conditions on the placement of sensors at vertices which enable the flow in the network to be uniquely determined. They proved that determining the optimal placement of sensors on vertices is NP-hard, and set up a couple of greedy heuristics to find lower and upper bounds on the amount of sensors for a set of randomly generated networks [14], [15]. Ehlert et al. proposed two extensions to previous methods of great practical relevance by means of integer linear programming: one solution takes existing detectors into account (referred to as the second-best solution), and the other takes flow information from the prior OD into account [16]. Gu et al. firstly studied the traffic sensor location problem using a minimum edge control set by modelling the traffic network as a digraph. They showed that for any strongly-connected directed graph with m edges and n vertices, $(m-n+1)$ sensors are needed to uniquely determine the flow value [18]. Chin et al. studied the problem of placing edge sensors on an undirected graph which is shown to be NP-hard, then presented two different approximation algorithms for the problem that run in polynomial time [21].

The remainder of this paper is organized as follows. Section 2 gives a short introduction to the engineering background of our research. Section 3 details how to transform the location problem to some graph problems and gives the problem formulation mathematically. Section 4 presents the algorithm to solve the problem and analyzes its performance. Section 5 is to verify the proposed algorithm with a graph example. Section 6 is devoted to some conclusions and open problems.

II. Engineering Background

One conventional detection method for vehicle emission is the so-called Vehicle Emission Field Testing Station (VEFES), an off-line and contact-type detection method. By simulating vehicles' driving mode (acceleration, deceleration, steady speed and idling speed) on the automobile chassis dynamometer, the accurate emission data is obtained. But the extremely long detection period results in the extremely low detection efficiency, and hence a car may be detected only once a year or even less often. Moreover, the cars are detected under the experimental situation, making that the data can not reveal the real-driving emission for the meteorology, driving habit, traffic condition and some other factors that are the co-factors determining the vehicle emission.

Being a complementary method for VEFES, the VERSS, composed of emission detection devices distributed to the road network, related accessory devices and data centre, can gather massive emission data in a short period. And the data can reflect the real-driving emission because the emission detection devices are on-road and have no affect on traffic flow. However, the data is not so accurate due to the fact that the emission plume is diffused by air disturbance immediately when emitted. Therefore, the data can not be directly used to judge whether a car is yellow-labelled or not. But we can still employ this system to make a rough filtering to separate the yellow-labelled cars out and then give them a further detection at VEFES to make the final decision.

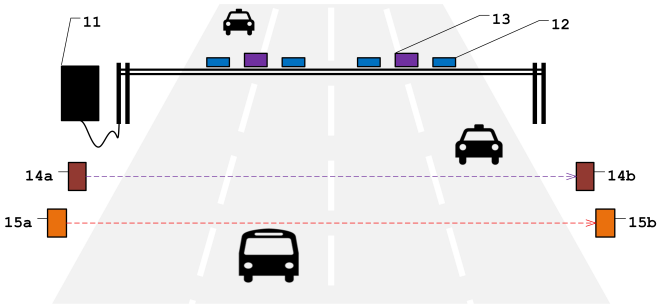


Fig. 1: Illustration of HEDD.

The development of VERSS is based on two types of emission detection devices: the horizontal emission detection device (HEDD) and the vertical emission detection device (VEDD). The horizontal emission detection device is composed of an industrial controller, a speed/acceleration sensor, a traffic monitor, an emission detector and a license recognizer, as shown in Fig. 1. The traffic monitor (13) is placed above the roads, monitoring traffic conditions of 2 to 4 lanes simultaneously. License information of passing vehicles are recognized and recorded by the license recognizers (12) over every lane. The emission detector (14) and speed/acceleration sensor (15) are placed on road-sides to measure the speed, acceleration and emission. The industrial controller (11) is employed to manage all components and also process data.

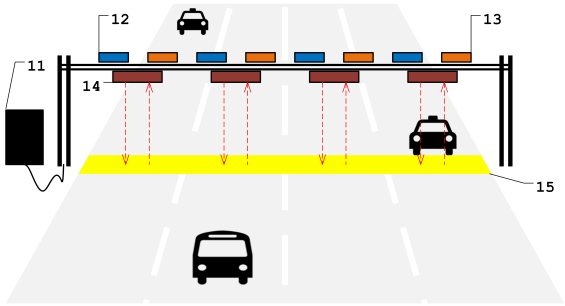


Fig. 2: Illustration of VEDD.

The vertical emission detection device consists of an industrial controller, a speed/acceleration sensor, an emission detector and a license recognizer. The traffic monitor is not involved because detection for all lanes is independent. As shown in Fig. 2, the speed/acceleration sensor (13), the emission detector (14) and license recognizers (12) are mounted onto the metal support. The main difference between the HEDD and the VEDD is that the latter has an integrated emitter and receiver. The receiver receives the laser, which

is generated by the emitter to the ground vertically, from the reflection area (15). Then the constituent and concentration of vehicle emission will be worked out according to the laser intensity reduction.

With different operating principal and system structure, the two devices have their advantages and drawbacks. Despite the higher accuracy than VEDD, the HEDD can only be used for light traffic condition, for it may fail if multiple vehicles are in parallel. On the other hand, the VEDD can be used almost everywhere without the consideration from heavy traffic. Hence, the VERSS is implemented by locating HEDDs and VEDDs on road traffic network to form a monitoring network. The remaining work is to design some location strategies to monitor vehicles as many as possible in real time with an acceptable cost, providing valuable information for vehicle emission which can then be used for the strategy-makers to design more pollution-aware policies.

III. Modelling and Problem Statement

An appropriate model contains information as much as possible without much data redundancy, and also should be a intuitional description to the real world. The urban road network contains a mass of roads parallel or cross themselves, coupled with the information related to these roads, e.g. driving limit, turn limit, road width and so on. This section details how to combine the location problem to some graph problems and give the problem formulation mathematically.

A. Definitions in Graph Theory

Before modelling the system some definitions are introduced. The graph-theoretic definitions are mainly referred to the textbooks cited in [22] and [23], where readers can get more information about graph and hypergraph theory, respectively.

A *digraph* is an ordered pair $D = (V(D), A(D))$ consisting of a set $V := V(D)$ of *vertices* and set $A := A(D)$, disjoint from $V(D)$, of *arcs*. The set V is finite and $A \subset V \times V$ is be unilateral relations on V. For an arc $a = \overrightarrow{xy}$, the a is said to *join* x to y. We also say that x *dominates* y. The vertex x is the *tail* of a and the vertex y its *head*. The number of vertices in D is referred to as *order* symbolically by $|V|$ and the number of arcs as *size* by $|A|$. The vertices which dominate a vertex v are its *in-neighbours*, and those vertices which are dominated by the vertex are its *out-neighbours*. They are denoted by $N_D^-(v)$ and $N_D^+(v)$, respectively.

A *directed walk* in a digraph D is an alternating sequence $W = v_0, a_1, v_1, \cdots, a_\ell, v_\ell$ such that v_{i-1} and v_i are the tail and head of a_i, respectively, $1 \leq i \leq \ell$ where the integer ℓ is the *length*. Here the vertex v_0 and v_ℓ are said to be origin and terminal, respectively. A *directed* (x, y)*-walk* is a walk from x to y and it is said that a vertex y is reachable from vertex x. If any two vertices in a digraph are mutually reachable, we say that the digraph is *strongly connected*. A directed walk with distinct arcs (or distinct vertices) are said to be *directed trail* (or *directed path*). The directed trail (or directed path) with identical origin and terminal are said to be *circuit* (or *cycle*).

A *set system* is an ordered pair $(V, \mathcal{F})$, where V is a finite set and $\mathcal{F} \subset 2^V$ is a family of subsets of V. Note that when $\mathcal{F}$ consists of pairs elements of V, the set system is a loopless graph. Thus they can be thought of as generalizations of graphs, and are usually referred to as *hypergraphs* symbolically by $H = (V(H), \mathcal{F}(H))$ where $V := V(H)$ is called set of *vertices* and $\mathcal{F} := \mathcal{F}(H)$ the set of *hyperedges*. The definition of *order* and *size* are similar to that of digraph, symbolically by $|V|$ and $|\mathcal{F}|$, respectively. A *simple hypergraph* is a hypergraph without repeated edges such that $F_i \subseteq F_j \Rightarrow i = j$. A *transversal* T of hypergraph $H = (V(H), \mathcal{F}(H))$ is a subset of V if it meets every edge i.e. $T \cap F_i \neq \emptyset$ for all $F_i \in \mathcal{F}$. If any proper subset of T is not a transversal, T is said to be *minimal transversal*. Let $\mathcal{T}$ denote the set of all minimal transversals of H. The hypergraph $TH = (V, \mathcal{T})$ is referred to as *transversal hypergraph*. The transversal with minimum cardinality is call *minimum transversal*.

B. Road Network Modelling

Many real-world situations can be conveniently described by means of a digraph consisting of a set of points together with lines joining certain pairs of these points, e.g. the urban road network composed of junctions and roads is highly similar to a digraph.

Definition 1. *Let digraph $D = (V(D), A(D))$ represent a road network where $V(D)$ represents the set of junctions and $A(D)$ the set of roads, respectively. The digraph D is strongly connected and without loops and parallel arcs.*

The junctions are locations where multiple roads intersect, allowing vehicular traffic to change from one road to another, so the junctions and roads can be seen as vertices and arcs, respectively. The definition only consider the connective function of a road from one junction to another with ignoring the other properties such as width and shape. This simplification is reasonable in this paper because the location problem is mainly concerned with traffic flow among these junctions and roads. It is noted that some junctions with heavy traffic are usually be designed as a circular intersection in which traffic flows are almost processing continuously in one direction around a central island. This kind of road can be simply treated as a junction for there are no functional differences compared with a common one.

Definition 2. *Let hypergraph $H = (X, \mathcal{I})$ represent the traffic circuit where X represents the set of roads and $\mathcal{I}$ the family of subsets of roads. $I_i \in \mathcal{I}$ is arc set of a circuit in D.*

Definition 3. *Let hypergraph $H = (X, \mathcal{C})$ represent the traffic cycle where X represents the set of roads and $\mathcal{C}$ the family of subsets of roads. $C_i \in \mathcal{C}$ is arc set of a cycle in D.*

The traffic circuit indicates that people drive their cars starting from someplace and finally back to the initial place with every road going through only once. The traffic cycle is similar to that of traffic circuit but the junctions are driven across only once. The two definitions are analogous to the

circuit and cycle in the digraph, which are established to describe the road network. To be a further simplification of a real-world road network, they abstract some more useful information for the location problem ignoring its topological property. It is worth noting that the traffic emission monitors are located on the roads only, so the set of junctions are dropped naturally.

C. Problem Statement

Traffic refers to all the vehicles that are moving along the roads in a particular area. Our purpose is to monitor the traffic emission, or to say, every car should be under monitoring no matter which route they choose to go. Such a purpose is achieved by placing traffic emission monitors on the roads which forms a monitoring network. Not surprisingly the amount and location of the sensors are key to the monitoring performance. Ideally the more detectors the system has, the better performance we can expect. However any realistic system is constrained by the economic considerations. Therefore, the balance between the cost and the performance, and consequently the optimization of the location of the sensors become one key technique in the remote sensing system.

With the graph-based model established, the subsequent analysis are all based on graph theory, where our location problem now is to find the set of arcs with minimum cardinality on which traffic emission monitors are installed, in order to guarantee that all on-road vehicles can pass through one of the monitors at least for once. Generally speaking, vehicles running on roads will pass the same point for more than once, regardless of the interval between two pass-by. That is because the characters of city resident trip, namely periodicity and regularity. We would have noticed the fact that on weekdays people usually drive their cars from home to their office or travel to meet with customers, and on rest days to entertainment places, supermarkets, or somewhere else, and then back home. So we assume that all on-road vehicles will be driven through a circuit in the traffic network. That is to say, if every circuit has at least one road located with a traffic emission monitor so every on-road car can be detected at least once. Hence this problem is converted to find the minimum transversal of $H = (X, \mathcal{I})$ where $X(H) = A(D)$. For the reason that every circuit contains a cycle at least, the hypergraph $H = (X, \mathcal{C})$ is essentially the simple hypergraph of $H = (X, \mathcal{I})$. So the location problem is to find the minimum transversal of $H = (X, \mathcal{C})$ instead of $H = (X, \mathcal{I})$.

IV. Location Strategy

We have developed a two-step method to solve this problem. In the first step, the depth-first search algorithm is employed to find all cycles to establish hypregraph-based set of cycle. In the second step, an approximation algorithm is designed to find the greedy transversal which are the roads to locate the traffic emission monitors.

A. Cycles Finding Algorithm

We discuss how to find all the cycles of the digraph D. Let $D = (V, A)$ be a strongly connected digraph. There is no vertex with its in-degree or out-degree equal to zero because these vertices are not on any directed cycle.

Ordering the vertices V by $1, 2, \cdots, |V|$, and starts from v_1 to search for the directed path $P = (v1, v2, \cdots, v_k)$ until P can not be extended any more. If there exists an arc $\overrightarrow{v_k v_1}$ at this step, a directed cycle $C = (v_1, v_2, \cdots, v_k)$ is obtained. Otherwise, return back to v_{k-1} based on the depth first principal and try to extend $P = (v1, v2, \cdots, v_{k-1})$ to another vertex. Repeating this step until it returns back to the origin v_1, all the directed paths starting from v_1 are searched and the related directed cycles are obtained. Repeat the procedure from next vertex to get all the directed cycles.

It is worth noting that: 1) In order to find the directed cycle with vertex v_i (if it does exist) by the searching from vertex v_i, the visited vertex can not be visited again at the extending of directed path; 2) The same directed path can not be used for more than once at its extending; 3) It should be avoided that the directed cycle with q vertices generate for q times, namely, it is obtained the same directed cycle at the searching from every vertex. Let v_i be the original vertex, it is achieved by not to visit the vertex v_j where $j \leq i$ at the extending of directed path. In other words, the original vertex of directed cycle should be the first in order.

The whole algorithm is based on the extending and shrink of the directed path, whose procedure performs as the push and pop of a stack with the last-in-first-out principal. We use P to represent the stack and t its top. Step 6 to 8 are the implementation of the three notations as presented before. The set S represents the next vertices that can be visited. At $S = \emptyset$ which means the directed path can not be extended any more, a judgement whether it can be composed to be a cycle by linking to the original vertex or not should be conducted, as shown from step 13 to 15. And then shrunk the directed path, namely, the top of P be popped, as shown from step 16 to 18. At $S \neq \emptyset$ which means the directed path can be extended, extending it and recording the visited vertices, as shown from step 20 to 24. A complete DFS ends at the directed path shrinks back to the original vertex, as shown from step 10 to 11. The similar search will be conducted for $|V| - 1$ times to ensure the completeness of cycles.

B. Minimum Transversal Finding Algorithm

To find a minimum transversal of a hypergraph is an NPC problem where the polynomial-time algorithm does not exist. It can be solved by applying the approximation algorithm based on the greedy concept which selects the best current option at each step without regarding to the future consequences. As can be imagined, such an approach rarely leads to an optimal solution but a polynomial-time procedure.

Algorithm. 2 will return a transversal of hypergraph H. Every step deletes the selected vertex and its intersecting hyperedges, a transversal is obtained until the hypergraph H is empty. The strategy to select vertex is to pick the vertex with the largest degree. If there are more than one vertices having the same largest degree, the first of them will be selected. There is no doubt that the greedy-based strategy can not ensure

Algorithm 1 Cycles Finding Algorithm (CF)

Input: a strongly connected digraph $D = (V, A)$
Initialize: a stack $P = \emptyset$, two sets $Q = \emptyset$ and $S = \emptyset$, two integers $\ell = 1$ and $t = 0$
Output: a hypergraph-based set of cycles $H = (X, \mathcal{C})$

for $i = 1$ to $|V| - 1$ **do**
  increment t by 1
  push v_i into P
  while 1 **do**
    set $S := N^+(v)$ where $v = P(t)$
    set $S := S - \{v_j : j \leq i\}$
    set $S := S - \{v : v \in P\}$
    set $S := S - \{v : \overrightarrow{uv} \in Q\}$ where $u = P(t)$
    if $S = \emptyset$ **then**
      if $P(t) = v_i$ **then**
        break the circulation
      end if
      if $\overrightarrow{uv_i} \in A$ where $u = P(t)$ **then**
        set $C_\ell := A(P)$
        increment ℓ by 1
      end if
      pop P
      decrement t by 1
    else
      push $S(1)$ into P
      increment t by 1
      add $\overrightarrow{uv}$ into Q where $u = P(t-1)$ and $v = P(t)$
      delete $\overrightarrow{uv}$ from Q where $u = P(t)$ and $v \in V$
    end if
  end while
end for
return $H = (X, \mathcal{C})$ where $X = A$ and $\mathcal{C} = \{C_1, C_2, \cdots\}$

Algorithm 2 Greedy Transversal Finding Algorithm (GTF)

Input: A simple hypergraph $H = (X, \mathcal{F})$
Initialize: $S_1 := H$, $T := \emptyset$, $i := 1$
Output: A transversal T of H

if $S_i \neq \emptyset$ **then**
  set $x_i := \emptyset$
  for $k = 1$ to $|X(S_i)|$ **do**
    if $d(x_i) < d(x_i^{(k)})$ where $x_i^{(k)} \in X(S_1)$ **then**
      set $x_i := x_i^{(k)}$
    end if
  end for
  add x_i into T
  increment i by 1
  set $S_i := S_{i-1} - S_{i-1}(x_i)$
end if
return T

the optimality of transversal, but the computation is quite low which can be implemented even in the large-scale situation.

V. Example and Results

In this section, a simple example is analysed in detail to explain how to implement the presented algorithm. Given the directed graph in Fig. 3 transformed from a geographic area where we plan to locate the traffic emission monitors, we will conduct the algorithm to find the minimum number of roads to detect all on-road vehicles.

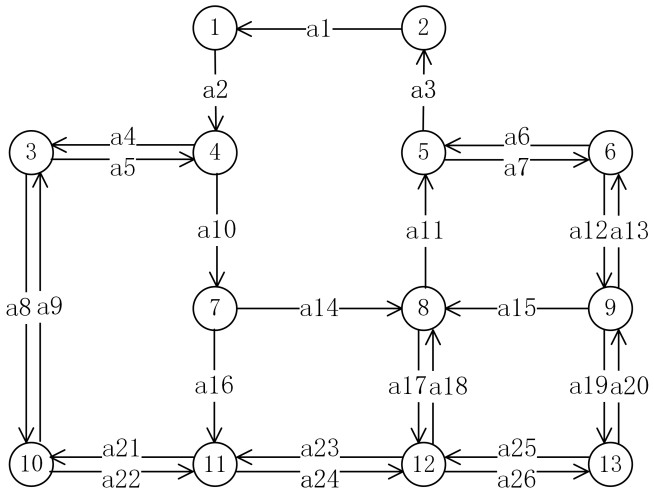


Fig. 3: Example of road network

As shown in the figure, there are 13 vertices and 26 arcs in the strongly connected digraph D. The vertex set and arc set are denoted by V and A respectively. The first step is to look for all the cycles in the digraph. Through the depth-first strategy, we obtain the set of all cycles $\mathcal{C} = \{C_1, C_2, \cdots, C_{23}\}$, where
$C_1 = [v_1, v_4, v_3, v_{10}, v_{11}, v_{12}, v_8, v_5, v_2]$;
$C_2 = [v_1, v_4, v_3, v_{10}, v_{11}, v_{12}, v_{13}, v_9, v_6, v_5, v_2]$;
$C_3 = [v_1, v_4, v_3, v_{10}, v_{11}, v_{12}, v_{13}, v_9, v_8, v_5, v_2]$;
$C_4 = [v_1, v_4, v_7, v_8, v_5, v_2]$;
$C_5 = [v_1, v_4, v_7, v_8, v_{12}, v_{13}, v_9, v_6, v_5, v_2]$;
$C_6 = [v_1, v_4, v_7, v_{11}, v_{12}, v_8, v_5, v_2]$;
$C_7 = [v_1, v_4, v_7, v_{11}, v_{12}, v_{13}, v_9, v_6, v_5, v_2]$;
$C_8 = [v_1, v_4, v_7, v_{11}, v_{12}, v_{13}, v_9, v_8, v_5, v_2]$;
$C_9 = [v_3, v_4, v_7, v_8, v_5, v_6, v_9, v_{13}, v_{12}, v_{11}, v_{10}]$;
$C_{10} = [v_3, v_4, v_7, v_8, v_{12}, v_{11}, v_{10}]$;
$C_{11} = [v_3, v_4, v_7, v_{11}, v_{10}]$;
$C_{12} = [v_3, v_4]$;
$C_{13} = [v_3, v_{10}]$;
$C_{14} = [v_5, v_6, v_9, v_8]$;
$C_{15} = [v_5, v_6, v_9, v_{13}, v_{12}, v_8]$;
$C_{16} = [v_5, v_6]$;
$C_{17} = [v_6, v_9]$;
$C_{18} = [v_8, v_{12}, v_{13}, v_9]$;
$C_{19} = [v_8, v_{12}]$;
$C_{20} = [v_9, v_{13}]$;
$C_{21} = [v_{10}, v_{11}]$;

$C_{22} = [v_{11}, v_{12}]$;
$C_{23} = [v_{12}, v_{13}]$.

Based on the cycles which has been found out above, the hypergraph-based sets of cycles $H = (X, \mathcal{C})$ can be established. The second step is to find the transversal of H. Applying the GTF algorithm the transversal T is obtained without the guarantee of optimality.

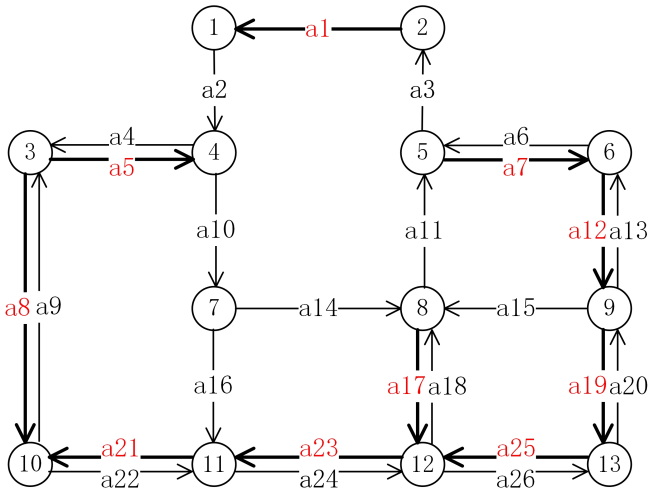


Fig. 4: The roads to locate monitors (red arcs)

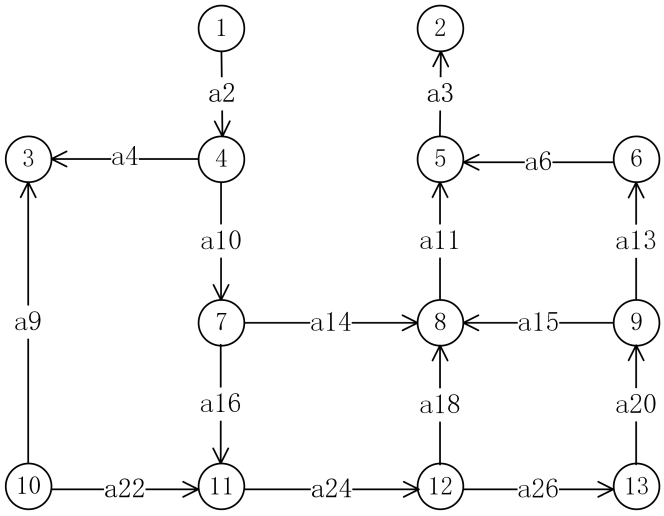


Fig. 5: The reminder road network by removing the red arcs

Fig. 4 shows the traffic emission monitors arrangement in the road network, and Fig. 5 shows the network by removing the roads that we selected, which contains no directed cycles any more. From Fig. 4 we realize that every two-way road need a monitor, because two arcs between a pair of adjacent vertices form a cycle $(C_{12}, C_{13}, C_{16}, C_{17}, C_{19}, C_{20}, C_{21}, C_{22}, C_{23})$. In the real traffic network, however, there is hardly any vehicle that just run on only one road, which means some more roads are actually not necessary to locate monitors. Some solutions to delete the redundant arcs should be performed subsequently, and this is a concern that also needs to be dealt with in our future studies.

VI. Conclusion and Open Problems

we propose a novel location problem in traffic network with some preliminary results. Due to the absence of existing works for this kind of location problem with the aim to detect all on-road vehicles, our efforts are not enough to fully resolve this problem. There are some important points that we should focus on in future research. For instance, there are lots of interactions of traffic flow between an area and its adjacent areas. Another pending issue is how to eliminate some redundant roads in the resulting set. We summarize some open problems in the future work.

- The temporal- and spatial-variation of road network;
- Whether a non-planar graph is an appropriate model;
- What will the algorithm be if the system is modelled as a arc-weighted graph;
- The inclusion of the failure probability of each device;
- A location strategy that every cycle is under the monitoring of at least n devices.

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1. Location problem for traffic emission monitors

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Abstract: In order to mitigate the air pollution caused by traffic, the monitoring of on-road vehicle emission is really an urgent issue. The Vehicle Emission Remote Sensing System (VERSS) is a promising technology to solve this problem. But there is scarcely any available location strategy for traffic emission monitors yet to our knowledge, which restraints the use of monitors on a large scale of traffic network. In this paper, we make some efforts to solve a novel location problem in the transportation domain, that is, we look for the minimum subset of roads on which traffic emission monitors should be located, thus we can detect as many on-road vehicles as possible. We explicate how to transform the location problem to some graph problems and give the problem formulation mathematically. Then a two-step algorithm is designed to find the set of roads to locate monitors. The simulation test verify its availability. And in the last section some problems that should be studied further are presented at the end of the paper. © 2016 IEEE.
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