A Design of Intelligent Route Guidance System Based on Shortest Path Algorithm

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***Abstract*—With the accelerated urbanization and the development of automobile industry, traffic congestion has become serious gradually for many metropolises. Thus, it is an important and extensive method in many countries to use the intelligent transportation systems (ITS) to control traffic and to induce vehicle flows so that road congestion may be mitigated and the traffic may be more efficient. As an important part of intelligent transportation, an intelligent route guidance system (IRGS) not only regulates traffic flow of every crossroads intersections to make full use of insufficient road infrastructure, but also reduces running distance and average waiting time for every driver to reach region traffic balance. This paper explores a design of IRGS and proposes a way to address the task decomposition of traffic guidance and path selection issues. Results from the simulation experiments suggest that IRGS with shortest path algorithm can achieve better network performance and increased traffic control system efficiency. The study provides theory and method guide for the development of real application system.**

***Keywords- Intelligent Route Guidance System; dynamic traffic assignment; task decomposition; shortest path algorithm*;**

I. INTRODUCTION

Along with the increasing tendency of global urbanization, more and more people flow into cities. This situation has led to severe difficulties in every aspect of society. For traffic management, the consequences are clear: in Beijing, between 2007 and 2012 the number of motor vehicles has increased by 66.7% (3.12 million to 5.20 million), which greatly affected the quality of life. The vast number of vehicles in city not only worsens the traffic quality and efficiency, but also increases time and money cost which leads to more serious traffic accidents, traffic jams and environmental pollution. Additionally, traffic phenomenon causes many social problems such as stress, air pollution, excessive fuel consumption, waste of time, etc. Traffic problem has become one of the major bottlenecks that restrict the development of many metropolises [1].

Traffic problem results from the imbalance between the limited supply and ever-increasing transportation demand [2]. The early road network expansion was regarded as a very effective solution to regulate road traffic. However, limited natural resource and costly labor-consuming made it not an ultimate way to solve the problem. Intelligent management of traffic system and acquainting drivers about traffic and road status can reduce curses of traffic congestion. So, the idea of "Intelligent Transportation Systems" (ITS), proposed in 1990s, offers us a new point of view to consider this problem. Intelligent traffic systems break through the bottleneck of tradition traffic signal controller and static traffic guidance, and make traffic control of big cities substantially intelligent. Optimization of road traffic flow would bring considerable and multi-aspect gains in daily life. The goal of ITS is to improve the transportation system to make it more efficient and safer by using various technologies which will save lives, time and money [3]. Besides the obvious economic benefits, more efficient traffic management leads to environmental benefits and improvements of life quality to drivers and passengers by reducing the circulation time of vehicles. The potential of ITS to provide solutions of the 21st century urban transportation problem has already been demonstrated in several piecewise applications. According to the Intelligent Transportation Society of America [4], the ITS encompass a broad range of wireless communications-based information, control and electronics technologies embedded in the system's infrastructure and vehicles to relieve congestion, improve safety and enhance productivity.

In this paper, we propose IRGS, which is Intelligent Route Guidance System, to provide effective and accurate intelligent traffic service by processing and analyzing dynamic traffic information, conducting road traffic real-time forecast and planning optimal drive routes in time. The simpler the guidance task is, the better goal can we achieve. This paper establishes a simplified urban multi-ring road system model, describes the principle of traffic guidance task decomposition and applies the shortest path algorithm to select optimal plans.

The result of simulation shows that IRGS has some advantages in traffic management over some existing methods.

To help you have a better understanding of our study, we outline the contributions of this paper as follows:

- We present a design of IRGS and divide it into four different subsystems, which are road network data collecting subsystem, vehicle-mounted terminal subsystem, data communication subsystem for traffic management and route optimizing subsystem. The structure and function of each subsystem are described in detail.
- We review classical route guidance system approaches based on dynamic traffic assignment and point the shortcomings of these approaches. Then, we propose a way to address the task decomposition of the traffic guidance and path selection issues.
- We evaluate the performance of IRGS via simulations using VISSIM. The simulation results show good approximation (to expected theoretical results), improved measurement gains and global traffic optimization compared to static centralized route guidance in dynamic traffic scenario.

The rest of the paper is organized as follows. The architecture of the system is presented in section Ⅱ along with detail information about its four subsystems. The proposed model and algorithm are explained in section Ⅲ. Section Ⅳ deals with the performance evaluation of proposed system with the help of VISSIM. Finally, the paper is concluded in section Ⅴ, which presents conclusion, commercialization of project and future scope for the proposed system.

II. THE FRAMEWORK OF IRGS

Traffic lights control and vehicle guidance are two basic part of intelligent transportation. While, traffic lights are a powerful tool to control and induce traffic flow compulsorily and passively, vehicle guidance has found great use in guiding and regulating traffic movements in an active and positive way, especially when traffic jams happen. IRGS should not only regulate traffic flow of every crossroads intersections to make full use of insufficient road infrastructure, but also reduce running distance and average waiting time for every driver to reach region traffic balance. From the point of traffic managers, with real-time traffic data collected by mass sensors, the system can provide a variety of personal services in terms of travelers' position, destination and preference. Meanwhile, in a view of users, after receiving guidance information, travelers can accordingly avoid congested road and choose optimal route, which in return helps to reach region balance. To some extent, traffic guidance is a kind of direct and positive adjustment to the traffic flow with specific purpose. To implement this system, the following work needs to be done:

- Collect past and present vehicle information (such as traffic density, vehicle speed, average intersection delay, etc) of region road network. This real data could be obtained by either manual counting at traffic junctions or using the probes such as loop inductors, CCTV cameras, etc [5].
- Form a model of short-time urban road traffic flow forecast with the help of past and current traffic information, and then, produce a road weight function which measures the crowdedness degree of detected road.
- Equip probe cars with embedded OBU (Onboard Unit) to detect traffic condition and use wireless communication as transmission module to exchange information with traffic data communication center. All these make probe car a source of traffic information.
- Assign different kinds of vehicles different priority levels, avoiding leading all users to the same shortest path, and consider traffic load on each road and origin-destination information from users' terminals to determine optimized route.
- Provide information about real-time road speed, travel time, accidents and construction areas to the public through all kinds of media. After receiving route guidance information, user terminals provide multi-mode guidance information including short message, voice service and dynamic maps.

Taken everything into consideration, the system must contain interconnection sub-modules responsible for traffic information detection, information exchange and database management, task decomposition and path selection, guidance information broadcasting. Excellent transplantable, reliable transmission and quick response are major characteristics of large-scale traffic guidance system. The operation of this system requires more assurances on the security of information transmission and maintenance of database. All these make IRGS an open and extensible distributed system with flexible compatibility, reliable transmission and quick response. The followings are 4 subsystems of an intelligent route guidance system: road network data collecting subsystem, vehicle-mounted terminal subsystem, data communication subsystem for traffic guidance and route optimizing subsystem. The structure and function of ITGS is shown in Figure 1.

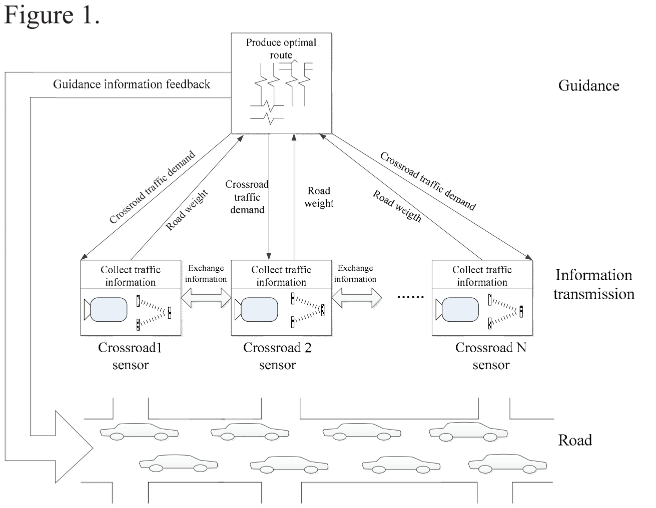

Fig. 1. Structure and function of ITGS (modified from [16])

A. Road network data collecting subsystem

The mass registered vehicle sensors comprise the data collecting subsystem of IRGS [6]. Many traffic data sensors based on different vehicle mechanics perform well in practical application in transportation field. These devices can be bought from various manufacturers and their measurement technique is advanced. Since the traffic data formats collected by different sensors are different, independent redundancy and flexible scalability must be considered when designing this subsystem.

However in practical, sensors are distributed far away from the traffic data center and the number of communication channels is limited. So we need to process observed data at local sensors using local decision rules. In order to improve the performance of route guidance, raw data should be sent to the fusion module within each sensor, and then decision from different sensors are being sent to route optimizing subsystem for final decision making [7].

B. Vehicle-mounted terminal subsystem

Conventional vehicle-mounted terminal systems generally provide vehicle positioning service based on GPS (Global Positioning Service) and GIS (Geography Information System), and produce optimal route according to drivers' preference. However, in practical, most of them rarely gives support to drivers' decision and even conversely causes complaint. It's the reason that they lack flexibility and intelligence when traffic condition changes that make them not good enough as predicted before.

There have been lots of commercial traffic guidance terminals based on static maps. However their performance is far from satisfactory. Firstly, during the peak time in some metropolises, most every street is blocked that it is very difficult for traffic guidance strategies to find a so-called optimal route. Then, if you are trapped in a traffic jam, they could hardly give you any valuable suggestions for the guidance strategies are fixed, which is the main cause of their low efficiency. Furthermore, those static traffic guidance terminals have no constrain for the drivers and some drivers will follow their own route instead of the recommended path, which makes the traffic guidance system not work at all [8].

Given the tremendous users and various applications of mobile terminal, portability, adaptability and independence are basic requires for the subsystem. User terminal with embedded OBU (Onboard Unit) and mini-sensor not only has basic functions on guidance inquiry, but also collects surrounding traffic information and transmit it to traffic information center. With the support of wireless communication over the whole network, vehicle-mounted terminals enrich the source of traffic data, which can be used for traffic flow prediction and route selection. Traffic situation and guidance information is received by vehicle terminal through its wireless transmission module.

C. Data communication subsystem for traffic guidance

The integration of GPS, GIS, computing technology and communication networks enables traffic guidance system to collect and process the real-time traffic information, accordingly to improve traffic information [9]. Data communication subsystem is responsible for the information interaction among information center, vehicle sensors and user terminals. Therefore, this subsystem is the core of implementing the functional aspect of IRGS. On the one hand, traffic data collected by vehicle sensors and user terminals is sent to route decision-making module through the wireless communication network. On the other hand, short-time traffic situation and guidance route feedback from optimizing subsystem is broadcasted to drivers over the network, which, as a result, mitigates traffic congestion. The reliable and frequent data transmission over the network ensures better performance and real-time response of IRGS. The total wireless network handing capacity must be large enough in case of any possible extension and exception.

The main function of wireless transmission mode in transportation field is to achieve accurate and real-time information exchange and large network capacity. Since vehicles move over road network at high speed and their behavior is hard to predict. Considering these characteristics and the need of wide area access and dual transmission for communication in traffic guidance system, not all the major wireless communication technologies are suitable for the real time transmission of traffic data [10]. Lots of work needs to be done to set up the network which meets the need of large-scale transmission of traffic information in wide areas both on capacity and transmission rate.

D. Route optimizing subsystem

Route optimizing subsystem, a fundamental part of IRGS, processes real-time information collected by vehicle sensors and probe cars and outputs optimal route plans for end users. Faced with millions of guidance inquiries, this subsystem is able to analyze and process traffic data, predict short-time traffic flow, and produce optimized route for drivers at a per-defined interval. Traffic assignment modeling and guidance algorithm are difficulties in the implementation of this subsystem, which directly affect the performance and efficiency of the whole road network. In the past 30 years, many scholars have undertaken lots of researches in this field and laid theoretical foundation for further study.

The uniqueness and convergence behavior of the solution algorithm are important not only from the standpoint of theoretical, but also in the view of their potential impact upon the relevance and reliability of model as a tool for policy assignment [11]. Moreover, the envisioned intelligent traffic guidance algorithm is supported by vehicle-to-vehicle and vehicle-to-infrastructure communications, allowing intelligent traffic management.

III. THE GUIDANCE SCHEME

In this section, we mainly describe the principle of guidance task decomposition for different vehicles and shortest path algorithm for each distributed route selection. Vehicles equipped with user terminals send traffic data and their guidance requests to the traffic information center and the route optimizing subsystem broadcasts traffic condition to the public and responses their requests.

A. Presentation of problems

Although the behavior of traffic flow has some similarities with compressible continuous fluid medium such as gas, their differences are clear. Call transmission model (CMT), a convergent numerical approximation to hydrocyanic model, replicated kinematic waves, queen formation and dissipation in an explicit manner. This capability makes it a suitable platform for modeling dynamic traffic. How to improve CTM or establish a new model for intelligent traffic management is where the difficulty lies.

In addition to traffic measurement, prediction of future traffic volume is very important to determining road weight precisely. Claudio Meneguzzer presented the circular structure, practical relevance, and the definition of Combined Traffic Signal Control and Route Guidance (CTSCRG) problem [12].CTSCRG models can provide the higher accuracy of network flow prediction as compared ordinary assignment models, which may improve the quality of real-time traffic information provided to drivers by route guidance system. The main challenges of designing such a model lie in overcoming the barrier of deployment and maintaining scalability and efficiency of route layer. The number of users of emerging route guidance services tends to grow exponentially, which makes it impossible treat the whole guidance requests as one control object. Therefore, it's important for traffic guidance to adopt suitable task decomposition strategy.

The routing guidance algorithms which only consider user satisfaction try to make sure that the user can reach the destination in shortest time. But those algorithms cannot balance the traffic load, for the reason that they lead all users to the same shortest path, and then the shortest path will get congested. The method considering traffic load on each road can have a good effect on balancing traffic density and reducing traffic congestions. It is necessary to take traffic load and user satisfaction into consideration at the same time, especially when the road density is high [13].

B. Guidance task decomposition

Our problem of road optimizing for urban traffic guidance needs a precise definition of object under consideration: road network. It is indeed a particular kind of graph and route guidance is a kind of algorithm for searching a graph aiming at finding the shortest path. We also define driving cost, which represents the real-time road density of a certain road.

Definition (Road network): A road network is a weighted directed multi-graph $G=(V, E)$, where V is a set of vertices denoting notable road elements: junctions, ends and E is a set of arcs (directed edges) representing road segment between vertices. We use a collection of adjacency lists to represent a graph G. Adjacency lists can readily be adapted to represent weighted graphs, that is, graphs for which each edge has an associated weight, typically given by a weight function $w: E \rightarrow \mathbf{R}$. For example, let $G=(V, E)$ be a weighted graph with weight function. The weight $w(u,v)$ of the edge $(u,v) \in E$ is simply stored with vertex v in u's adjacency list.

After receiving the position and destination information from a user terminal, the route optimizing subsystem treats it as a pair of origin-destination (OD). And, the information collected by vehicle sensors and probe cars is processed to get road weight $w(u,v)$, which varies according to different traffic conditions. The self-adaptation identification method of urban traffic conditions shows positive and encouraging results and has a high accuracy and robustness [14]. We can assign different kinds of vehicles different priority levels to avoid leading all users to the same shortest path. Suppose that the priority of Emergency Ambulance or Fire Bridge or Police Vehicle is higher than that of cars, which is higher than that of truck. In order to cope with the exponential increase of traffic guidance requests, we use a distributed traffic guidance mechanism. The followings are the processes of guidance task decomposition in our proposed method in detail.

Step 1. The whole traffic guidance task G can be divided into different sets of subtask according to different OD pairs, such as $G=(G_1, G_2 \ldots G_n)$. A subtask can be the traffic guidance of the same OD pair vehicles or route selection of a single vehicle.

Step 2. Given the component of the same OD route guidance subtask G_i, the following two situations need be considered.

1) If subtask G_i contains vehicles of different priority levels, G_i must be finished in the sequence of priority level from high to low. After route guidance of high priority vehicles finished, the prediction of future road weight need to be updated.

2) If subtask G_i contains vehicles of single priority level, shortest route guidance only needs to be done once to solve the problem [15].

C. Shortest path algorithm

The Bellman-Ford algorithm solves the single source shortest-path problem in the general case. Let's explain it in detail. This algorithm uses the technique of relaxation. For each $v \in V$, we maintain an attribute $v.d$, which is an upper bound on the weight of a shortest path from source s to v. We call $v.d$ a shortest-path estimate.

We often wish to computer not only shortest-path weights, but the vertices on the shortest paths as well. Given a graph $G=(V, E)$, we maintain for each vertex v a predecessor $v.\pi$ that is either another vertex or NIL. The shortest algorithm set π attributes so that the chain of the predecessors originating at a vertex v runs backwards along a shortest path from s to v. Thus, given a vertex v for which $v.\pi \neq$NIL, the procedure Print- path (G,s,v) can be used to print a shortest path from s to v. The Bellman-Ford algorithm uses relaxation, progressively decreasing an estimate $v.d$ on the weight of a shortest path from the source s to each vertex $v \in V$ until it achieves the actual shortest-path weigh $\delta(s,v)$. The following pseudo code shows the execution of the Bellman-Ford algorithm [16].

Bellman-Ford Algorithm

```
input  : A road network G=(V,E); a weight function w
output : the shortest path from s to v
begin
  // Initialize-single-source(G,s)
  for each vertex v ∈ G. V
      v.d=∞
      v.π=NIL
  s.d=0
  for i= 1 to |G. V| − 1
      for each edge(u,v) ∈ G. E
          // Relax(u,v,w)
          if v.d>u.d+w(u,v)
              v.d=u.d+w(u,v)
              v.π=u
  //Print shortest path
  Print-path(G,s,v)
  if v==s
      print s
  else if v.π==NIL
      print "no path from" s "to" v "exists"
  else  Print-path(G,s,v.π)
  print v
end
```

IV. SIMULATION RESULTS

The validation of the performance of IRGS algorithms in urban environments is very complex to achieve in real experiments. Traffic simulation is the process of simulating transportation systems through software on a virtual road network, which helps in analyzing city traffic at different time intervals of a signal day, estimating traffic demand at particular junction and so on. These tools are needed to enable these studies in simulation at microscopic level. With VISSIM, complex traffic situations can be simulated and the performance of different ITS algorithms can be evaluated.

In order to validate the model and algorithm of IRGS, a simple road network is shown in Figure 2. The simplified case-study is composed by 17 main roads and 9 crossroads intersections (CI) and the length of each road is shown in picture. Expected capacity of this road network is 2400pcu/h. Suppose that traffic situation is regarded as congested when total network capacity is over 3600puc/h (1.5 times of expected capacity), a very loose upper bound.

In this figure the junctions are shown by letters U. In the CI, vehicles arrival/depart from four directions and two roads of inflow/outflow per direction and two lanes per road. The generating of vehicles subjects to binomial distribution or Poisson distribution and Emergency Ambulance or Fire Bridge or Police Vehicle, car and truck makes up 5%, 65% and 35% of the whole vehicles receptively. The free speed is 40km/h. There are traffic lights in each CI and their cycle and phase are fixed. Inside the CI box junction vehicles are not allowed to stop, which means that a vehicle must not enter the box junction if there is no space for the vehicle to exit in the desired CI output destination. No overtaking maneuvers are considered in this study [17]. Suppose that 70% of vehicles obey the guidance recommended by the route optimizing subsystem. The simulation starts at 8:00am, morning peak time, and lasts 3 hours.

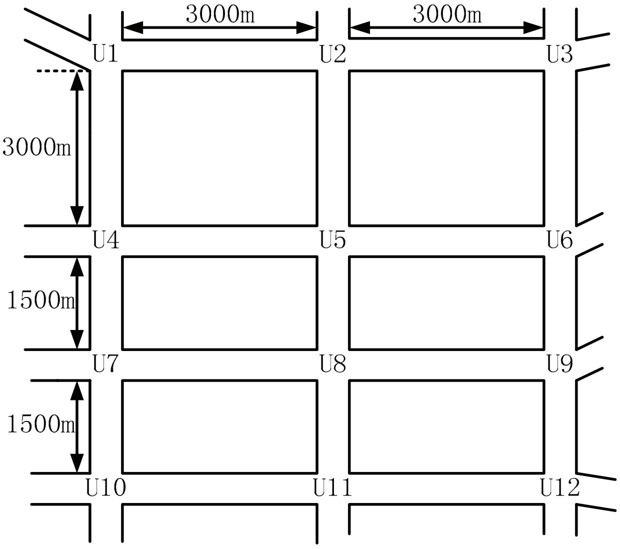

Fig. 2. Simplified case-study scenario

In order to estimate the guidance scheme proposed in this paper, we follow the tracks of two vehicles A and B with the same OD. The vehicle A's priority level is higher than B's. The process of route guidance for vehicle A and B is shown in Table 1.

Table I：route guidance for vehicle A and B with the same OD

Time	route guidance for vehicle A（high priority level）	route guidance for vehicle B（low priority level）
8:00	1->2->5->6->9->12	1->4->7->8->11->12
8:05	2->5->8->9->12	4->5->6->9->12
8:10	5->8->11->12	4->7->8->9->12
8:13	8->11->12	7->8->11->12
8:17	11->12	
8:19		8->11->12
8:21		11->12
Actual driving route	1->2->5->8->11->12	1->4->7->8->11->12

Based on the simulation results given, it would be discovered that vehicle A arrived at U12 earlier than vehicle B, which is the result of guidance task decomposition and the difference of their priority levels. As shown in Tab. I, simulation results have confirmed the feasibility and efficiency of guidance task decomposition and dynamic route selection proposed in the paper.

It's a simple matter to generalized IRGS and apply it to more complex traffic situation, when road load changes in a wide range. In VISSIM, we can load traffic demand through Matrix OD, which represents the traffic flow among each CI at a certain internal. Performance evaluation criteria of IRGS are average waiting time of a vehicle, average speed with or without guidance. After 5 times simulations, the average values of evaluation criteria are calculated out and are shown in Fig. 3 and 4.

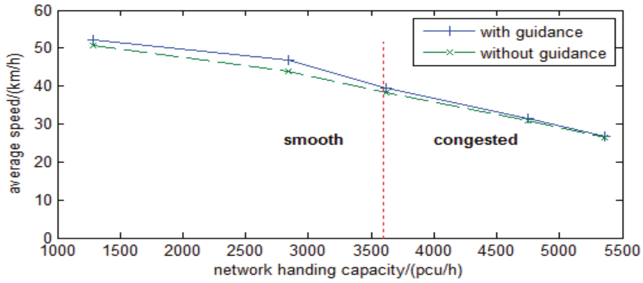

Fig. 3. Average speed vs. network handing capacity

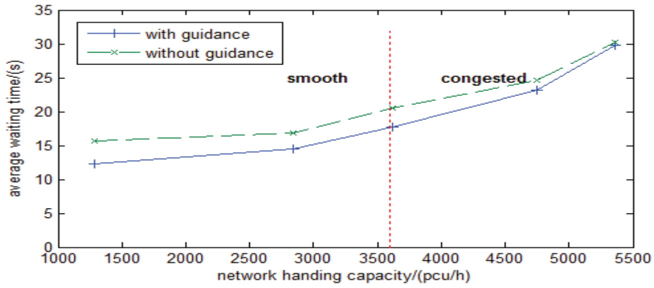

Fig. 4. Average waiting time vs. network handing capacity

From Fig. 3 and 4, it would be realized that when vehicle flow runs smoothly, with the help of IRGS, average speed is increased at most by 6.6% (43.9km/h to 46.8km/h), meanwhile waiting time is decreased by 16.1% (16.89s to 14.55s). Furthermore, great value of dynamic guidance can be found when traffic jams happen (network handing capacity is 4744pcu/h>3600puc/h), saving 9.89% of average waiting time (24.56s to 22.13s). We can conclude that IRGS helps to regulate traffic flow, reduce travel time for drivers and improve the efficiency of network.

V. CONCLUSION

With well designed structure and function of its four subsystems, the proposed traffic guidance system based on shortest path algorithm can fulfill the guidance task for drivers. The system considers the requirement on the accuracy of data collection, reliability of wireless transmission and variety of information broadcasting. Results from the simulation results suggest that IRGS with shortest path algorithm is able to reduce running distance and average waiting time for every to achieve region traffic balance. The application of IRGS can reasonably mitigate traffic congestion, utilize insufficient road infrastructure and achieve better network performance.

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