A DECENTRALIZED ROUTE GUIDANCE ALGORITHM IN URBAN TRANSPORTATION NETWORKS

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Abstract: In the last decades, due to the increasing car traffic and the limited capacity of urban networks, algorithms for traffic management and route guidance are becoming more and more important. GPS technology can be used for fleet monitoring in urban or suburban areas, from a central monitoring station and may provide useful information concerning the movement of all vehicles. Current route guidance systems are simple from an algorithmic point of view (they compute shortest paths to the destination), but they have to deal with huge size networks. For this reason, a decentralized approach, in which each vehicle independently calculates its own route, is desirable. Naturally, to limit the congestion due the vehicles decisions, an estimate on the different possible routes is required. Hence, we propose a decentralized algorithm in which each vehicle computes its own route on the basis of the traffic information provided by the reference station. Moreover, we propose a method for forcing vehicles to choose different paths and for informing the reference station on the routes of all vehicles, so that traffic forecast is updated.

1 INTRODUCTION

The steadily growing car traffic and the limited capacity of our streets demonstrate the necessity of designing methods for better traffic management. Studies [Jahn et al. 1999] show that an individual "blind" choice of routes leads to travel times that are between 6% and 19% longer than necessary. Electronic and sensory devices are becoming more popular and they provide or will shortly provide detailed information about the actual traffic flows, thus making available the necessary data to employ better means of traffic management. So, the focus is on developing Intelligent Transportation Systems that are capable of better managing existing capacity and encouraging more efficient vehicle routing over time and space.

Many vehicles get equipped with the so-called route guidance systems. They guide the driver from the origin to the destination by visual and acoustic indicators. These systems in order to compute their routes need digital maps, the current position obtained by Global Position Systems (GPS), and possibly up-to-date traffic data, which are broadcast by radio or cellular phone. Most inefficiencies caused by human route choice can be reduced by route guidance systems, obtaining a better use of the whole network. Unfortunately, many simulations also predict that these benefits will be lost once the number of equipped vehicles exceeds a certain threshold. In fact, it is possible that such system actually causes congestion, if the algorithms try to minimize the individual journey time of each driver separately, without taking into account the effects of their own route recommendation. Thus, the need for integrated algorithms that actually take into consideration the overall road usage (which can be viewed as the sum of all individual journey times) has been recognized.

2 BASIC STRUCTURE OF ROUTE GUIDANCE PROBLEMS

In the literature there are essential two different approaches to route guidance problems: one researches the *system optimum*, the other the *user equilibrium.* When the interest is in minimizing the total travel time, the best is to consider a global perspective and compute the *system optimum*. In this case, the existing road network may carry more traffic [Wardrop 1952]. Unfortunately, this policy may route some drivers on unacceptable long paths in order to use shorter path for many other drivers. The length of a route in the system optimum can be

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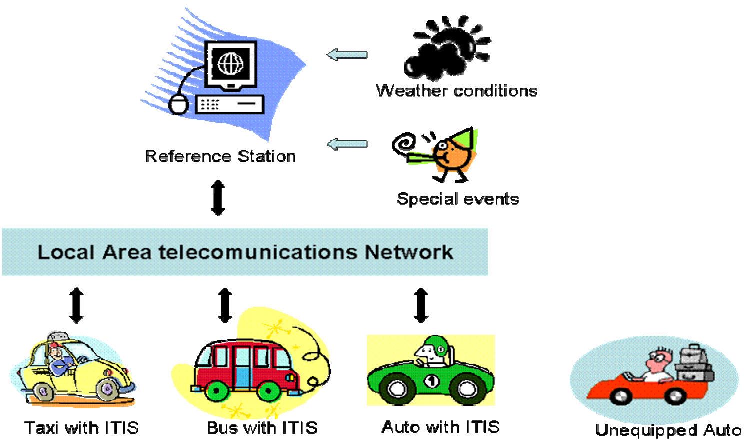

Figure 1: Conceptualized distributed transportation network.

significantly higher than in the *user equilibrium* [Roughgarden and Tardos 2000]. The main drawback of this approach is that after a while a user may be unsatisfied and stop using the route guidance system.

On the other hand, when minimizing individual journey times of each driver, we can be far from the system equilibrium. Many algorithms try to minimize individual journey times, without taking into account the effects of their route recommendation. Under current systems, many drivers could be given exactly the same route recommendation. Therefore, assuming similar mean speed, some drivers may always stay together on their trip (*platooning*), and this may possibly lead to congestion. While Adler and Blue [1998] call this phenomenon *oversaturation*, Ben-Alkiva. De Palma and Kaysi [1991] call it *overreaction*, since too many drivers follow the recommended route. To deal with this problem, it is essential to split platoons over several paths (*multiple path routing*). Many authors have proposed different approaches to deal with multiple path routing. Rilett and Van Aerde [1996] suggest adding individual random error terms to the road travel times broadcast by a central controller, in order to cause the in-vehicle computers to choose different paths. Lee [1994] computes *k*-shortest every ten minutes and then distributes drivers over them every two minutes, considering the current travel times on these paths.

Another popular approach is to route drivers along the paths of so-called *user equilibrium*, so that no driver can get a quicker path through the network by unilaterally changing his route [Fresz T. L., 1985]. This concept was introduced to model natural driver behaviour and it has been studied extensively in the literature.

In our work we assume that connected users are provided with an Intelligent Traveller Information System (ITIS) capable of providing route guidance and/or traffic advice both pre-trip and while en-route. ITIS is a term coined by Adler and Blue [2002] to describe next generation information devices that can gather and process information as well as learn and represent user preferences and behaviour.

3 PROBLEM DEFINITON AND PROPERTIES

A traffic network, represented by a direct graph $G=(N,A)$, consists of a set of $|N|$ of nodes and a set of $|A|$ links. Consider a situation in which a vehicle with ITIS (*Intelligent Traveller Information System,* see Figure 1) is currently travelling on link (i,s) towards the destination node d, we want find on which link (s,j) the vehicle should enter next, so as to minimize the expected travel time to the destination node d.

It is assumed that the local controller (i.e. a vehicle with ITIS) has available complete information on the topology of sub network G′ (the network representing all candidate paths from origin o to destination d of the interested vehicle) and current estimates of travel times on individual links.

Traffic flows have two important features that make them difficult to study mathematically. One is “congestion”, and the other is “time”. Congestion captures the fact that travel times increase with the amount of flow on the streets, while time refers to the movement of vehicles along paths as “flow over time”.

Congestion implies that transit time t_e is not a constant, but monotonically increases with the augmentation of the flow value x_e..

Flow variation over time is an important feature in network flow problem arising in various applications such as road or air traffic control, production systems, and communication network.

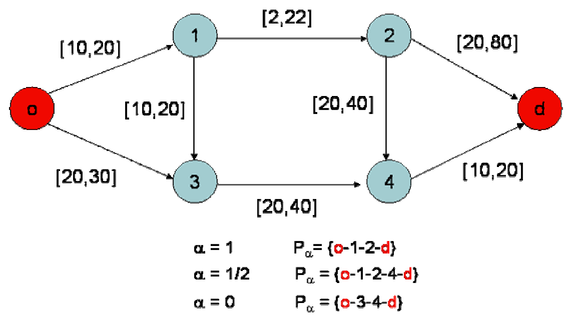

Figure 2: A very simple example.

Ford and Fulkerson [1958] observe that flow-over-time problems in a given network with transit times on the arcs can be transformed into equivalent static flow problems in the corresponding *time expanded network*.

4 DECENTRALIZED APPROACH

In many different areas of manufacturing, traffic network, medicine, software engineering and etc., the decentralized approach reaches good performances. Obviously, when all data are available and of reasonable size, it is always possible to use a centralized approach.

Naturally, a user will buy a route guidance system only if he can obtain a benefit, but a system optimum is not always a good solution from a user point of view. Probably, a driver is induced to use a route guidance system, if he/she is confident and sure that the recommended route is always a good route for him/her. In our work, we consider a decentralized decision approach, where each driver selects his/her route, on the basis of the traffic on the network.

We consider a hierarchical structure with two different levels: at a *high level* there is a *reference station*, that represents a sort of real time database, where all information related to the traffic on the network are available; at the *local level* is present a local controller (*Intelligent Traveller Information System ITIS*). The reference station is responsible for management functions such as collecting and storing data, gathered from the network, and disseminating traveller information.

Figure 1 depicts the set of travellers and flow entities seeking to travel through the network.

4.1 Path computation

Each vehicle with ITIS calculates its path from the origin o to destination d on the basis of some information that is exchanged with the reference station. For each link of the traffic network we know the estimated minimum transit time t^e_{min} and the estimated maximum transit time t^e_{max}. These two parameters are calculated at the high level on the basis of real-time, collected and stored data. For each link e

t^e_{min} is a lower bound on the transit time (dependent on flow) on e;

t^e_{max} is an upper bound on the transit time (dependent on flow) on e.

As we will discuss in the next section, the value t^e_{max} can be calculated also by considering the vehicles that are in the network, but have not decided their route yet.

Each vehicle v , when computing its optimal route from o^v to d^v, assumes that the transit time on arc e is:

$$t^e = \alpha^v\, t^e_{\min} + (1-\alpha^v)\, t^e_{\max}$$

The parameter α^v is a characteristic of the ITIS, it is a real number $\alpha^v \in[0,1]$. This *characteristic index* α^v of the vehicle allows us to determine different paths and avoid congestion on some links. A very simple example in which different paths corresponds to different values for α^v is depicted in Figure 2.

4.1.1 Potential flow evaluation

We introduce the concept of potential flow as a way of providing an estimate on transit times in the immediate future by considering vehicles with ITIS that are in the network, but have not decided their route yet. Then, the *potential flow* represents all users that have requested information on the traffic of the network but have not calculated their personal route yet. Naturally, it is necessary to have an evaluation of these potential users to eliminate the platooning effect.

Here, we consider two different ways to calculate potential flow (in Figure 3 there is an example of the two different potential flow evaluations). Since traffic networks are usually very large and since

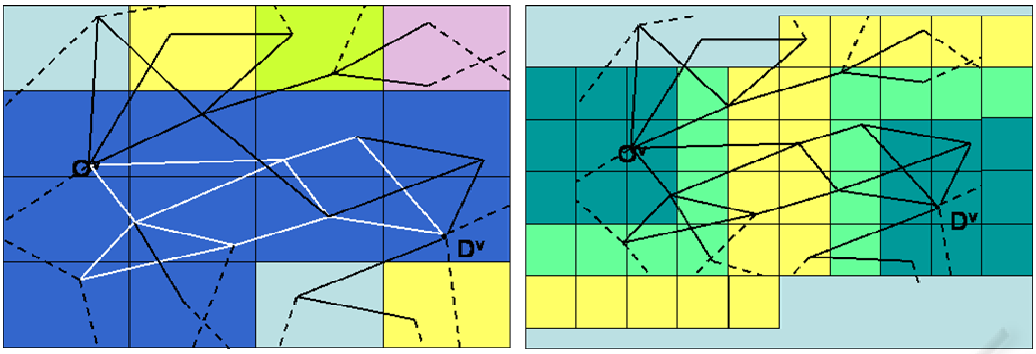

Figure 3: An example of potential flow evaluation in cases (a) and (b).

detailed information might not be necessary, we divide the network G in different areas or sectors and we proceed as follows.

Case (a): For each vehicle v we consider all paths not exceeding a certain length from its origin o^v to destination d^v. A vehicle v is *part of a potential flow* for a sector s if an arc of its path is in sector s.

Case (b): For each vehicle v we consider a fixed dimension (D) neighborhood of its origin o^v and its destination d^v. This dimension D is related to the dimension of the sector. The neighbourhoods grow until they meet each other and the dimension of the overlapping area is at least D (in Figure 4, there is an example with D=3). A vehicle v is a part of a potential flow for every arc in the neighbourhoods.

We are currently running some tests in order to evaluate which level of information is requested to obtain a good solution and to determine the best tradeoffs between detailed information and running times.

5 CONCLUSIONS

In this work we are trying to utilize decentralized approach for a hard problem like the route-guidance problem. We have proposed a simple approach to find a compromise between single users satisfaction and global utilization of the network.

We are still at a preliminary stage of our research. We are setting up a simulation, using algorithm A* to calculate shortest paths, in order to evaluate how the different choices for α^v lead to different paths.

REFERENCES

Adler J. L., Blue V. J., 1998. *Toward the design of intelligent traveller information systems*. Transportation Research C, 6:157-172.

Adler J. L., Blue V. J, 2002. *A cooperative Multi-agent transportation management and route guidance system*. Transportation Research C. 433-454.

Ben-Akiva M. E., De Palma A. , and Kaysi I., 1991. *Dynamic network models and driver* . Transportation Research A, 25:251-266.

Ford L. R., Fulkerson D. R., 1958. *Constructing maximal dynamic flows from static flows.* Operations Research 6: 418-433.

Fresz T. L., 1985. *Transportation network equilibrium design and aggregation: key development and research opportunities*. Transportation Research A., 19:413-427.

Jahn O., Möhring R. H., Schulz A. S., Stier Moses N. E., 2002. *System Optimal Routing of Traffic Flows with User Constraints in Networks with Congestion*, Technical Report 754/2002 Technische Universität Berlin.

Jahn O., Möhring R. H., Schulz A. S., 1999. *Optimal Routing of Traffic flows with length restrictions in networks with congestion.* Technical Report 658/1999 Technische Universität Berlin.

Lee C. K., 1994. *A multiple-path routing strategy for route guidance systems*. Transportation research C, 2:185-195.

Rilett L.R., van Aerde M. W., 1991. *Modeling distributed real-time guidance strategies in a traffic network that exhibits the Braess paradox.* In proceedings of IEEE Vehicle Navigation and Information Systems Conference.

Roughgarden T., Tardos E., 2000. *How bad is selfish routing?*. In proc. of the 41st annual IEEE, symposium on foundation of computer science FOX'00.

Wardrop J. G., 1952. *Some theoretical aspects of road traffic research* ,Proceeding of the Institution of civil engineers.