Łukasz CHOMĄTEK

Lodz University of Technology

Adaptation of artificial hierarchical division of the road network to different traffic conditions

***Abstract**. In this article an algorithm for adaptation of the artificial hierarchical division of the road network to different traffic conditions is presented. The algorithm is an extension of the known Highway Hierarchies algoritm. After application of the proposed improvements, obtained results revealed the reduction of the computational time required for finding optimal path between two points on the map. What is more, presented algorithm can be applied in case of solving dynamic Vehicle Routing Problem.*

***Streszczenie.** W niniejszym artykule zaprezentowano algorytm adaptacji sztucznego podziału hierarchicznego sieci drogowej do zmiennych warunków natężenia ruchu. Algorytm jest rozwinięciem algorytmu Highway Hierarchies. Po zastosowaniu zaproponowanych przez autorów zmian otrzymano redukcję czasu obliczeniowego potrzebnego do wyznaczenia optymalnej trasy pomiędzy punktami w grafie połączeń drogowych. (**Adaptacja sztucznego podziału hierarchicznego sieci drogowej do zmiennych warunków natężenia ruchu**)*

Keywords: road network hierarchical division, Parallel Hierarchies, Dynamic Vehicle Routing Problem.
Słowa kluczowe: podział hierarchiczny sieci drogowej, dynamiczny problem marszrutyzacji

Introduction

Efficient vehicle routing is one of the major problems in most cities. Complexity of the road network causes the need of the efficient algorithms for finding the optimal routes between points on the map. Such algorithms are often implemented either to work on personal car navigation system or as an online services. Limited resources of personal devices as well as growing number of users of the web-based systems exacts optimization of the algorithms computational complexity and the memory usage.

Classical algorithms for finding optimal itineraries for drivers are based on the priority queue, where each node's priority is calculated in different methods. Modern approahes for this problem are based on the hierarchical division of the road network. Such a division is usually provided by the country authorities, but hardly ever can be directly utilized for the efficient route calculations. Mentioned algorithms consist of two phases: construction of the hierarchy levels and actual querying. Artificial hierarchical division of the road network causes the reduction of the number of road segments which can be analysed during the search. Such a division can be treated as an improvement for existing algorithms that limit search space by adding some spatial information to the search. Due to their efficiency, hierarchy based algorithms are usually applied, when the low computational complexity of a single query is crucial.

Vehicle routing problem (VRP) is present in computer sience for over fifty years. However in its first definition problem took into account the static case, where the travel costs for each pair of customers were known *a priori*, in recent works requirements are completely different. In most of considered problems both distances and positions of the customers can differ in time. What is more, other constraints like capacities of the vehicles need to be reflected. For calculations of routes in the dynamic VRPs, a good point is to apply hierarchical algorithms for optimizing routes between the clients.

In this article authors propose an adaptation of the known algorithm for solving Single Source Shortest Path Problem (SSSP) for the case of dynamic VRP. Mentioned algorithm, named Parallel Hierarchies allows to adapt the optimal path to different traffic conditions as well as reflect the situation, where transport request from customers can appear dynamically in time. Due to the parallel implementation, proposed algorithm offers computational time reduction of executed User's queries. What is more, simple adjustments of the parameters of the algorithm takes effect in the different problems.

The article is organized as follows: in the first section authors present state of the art and the definition for the Vehicle Routing Problem as well as the possiblity of the use of traffic counts for solving this class of problems. Second section contains a brief description of the hierarchical algorithm for solving dynamic vehicle routing problem. In the third section obtained results are gathered for problems of attraction and distraction drivers to or from certain places respectively. Conclusions and plans for future work are outlined in the end.

Vehicle Routing Problem

The problem of vehicle routing is present in computer science for almost fifty years [1]. As many aspects can be taken in the account when considering vehicle routing, the problem cannot be easily defined. Generally speaking, Vehicle Routing Problem regards designing optimal delivery from one or several depots to a number of geographically distributed cities or customers [2]. Solution is a set of least-cost vehicle routes, that:

- each city is visited exactly once by exactly one vehicle,
- all vehicles start and finishes their routes in the depot,
- other task-specific constraints are satisfied.

Mentioned side constraints can include:

- limited capacity of each vehicle (CVRP),
- limited duration of route (DVRP),
- customer can be visited only in specified time interval (TW-VRP),
- one customer must be visited before other customer is visited.

Obviously, least-cost does not always mean "shortest". There can be different criteria to identify values of weights for each of road segments.

One can identify four classes of routing problems. In static and deterministic problems, input information is known beforehand and vehicle routes does not change during the execution of the prepared plan. Such a situation appears hardly ever in reality. Static and stochastic problem exists if input is partially known, so that requests can change when vehicles are on route. Travelling costs does not change in this case.

Dynamic routing problems are more complicated cases. New requests may appear during the trip and they're not known at the start of the planning algorithm. In some works, authors assume that driver can have some information about new tasks when he is heading to one of the destinations. This means that he can make a decision to take another route by himself.

For dynamic and deterministic routing problems some exact methods can be used to calculate the optimal solution. One should notice that in case of dynamically appearing tasks, planned route is only valid for the current state (position of the driver, actual time and tasks assigned). If any change occurs, whole route must be replanned.

Authors of [3] analyze the problem of trucks transporting some goods. Trucks receive their tasks dynamically. Authors proposed the solution based on the linear programming (LP). Recalculation of the itinerary was needed each time new task was assigned.

In case of dynamically appearing requests some heuristic must be used for large scale problems. First idea of such a solution was presented in [4] by Gendreau et al. The general idea was to keep a pool of good solution in the structure denoted as adaptive memory, which is utilized to initialize the parallel tabu search. In this work each route in current solution is optimized in the separated threads. Vehicles are usually not allowed to change their route until they finish the processing of the current request.

Other approach, known as Multiple Plan Approach (MPA) was proposed in [5]. Population of possible plans was used to generate a new solution. If a new

request appears, it is checked if current vehicle can process it. If so, solutions that can't handle the new situation are discarded.

Dynamic VRP can also be handled by genetic [6] or Ant Colony Optimization algorithms [7]. In stochastic cases, two main paths of research can be

identified: first group of algorithms is based on the stochastic modeling and the other is based on sampling. In this paper we will focus only on the second group, as our solution is based on this method.

Sampling [8] is understood as the generation of scenarios focused on the handling of unknown requests. Potential places of visit are identified and added to the trip schedule. After creating the itinerary, this virtual locations are deleted. When new request appear in the system it will be handled with a lower cost.

Traffic counters

Optimization of the traffic flows usually consist of proper setup of the signals and traffic lanes allocation. To perform such an optimization one need to have information about actual traffic conditions which can be collected by counting vehicles. Nowadays, instead of the manual observation, modern methods are applied. In this section authors summarize the classification of the traffic counters.

Such devices can be divided into intrusive and non-intrusive. Intrusive are those installed into the lanes or in top of them. Conversely, non-intrusive do not interfere with traffic flow during their operation.

In the first group, most popular methods of counting the traffic are: bending plates, inductive loops and piezoelectric sensors. In the second one: infrared beams, radars, and video image detection.

Bending plates consist of the weight pad attached to a metal frame installed into the lane. Passing vehicle causes the frame to bend, so that it yields the weight based on axle load. Having two bending plates installed into a single lane allows to measure the vehicle's speed.

Piezoelectric sensors works similarly to the bending plates. When a vehicle passes through the sensor, mechanical deformation of the piezoelectric material causes a change in the surface charge density of the material, so that voltage on the attached electrodes changes as well. This method allows to control both speed and weight of the passing vehicles.

Inductive loops are wires embedded under the roadway. In this case, vehicles act as the magnetic field and the loop as the electrical conductor.

Infrared devices emit a laser beam at the road surface and measure the time for the reflected signal to return to the device. Passing vehicle causes the reduction of this time. The method of measuring the time is also utilized in the radar based methods.

Vision based methods are supposed to detect the presence of the vehicle in certain zones. What is more some kind of the tracking can be applied.

In most systems for traffic optimization data from different traffic counting devices is collected and merged to obtain final input for the algorithms.

Proposed hierarchical algorithm

Modern algorithms for solving SSSP problem are usually try to reduction number of nodes visited during the search as well as number of edges in the road network. First goal can be achieved by reflecting spatial information (A*, ALT). Second one requires some kind of division performed on the road network to assign road segments to some classes.

One of the most popular hierarchical algorithms which is based on the hierarchical division of the road network is Highway Hierarchies. The algorithm is derived from the observation of real drivers behavior who must have a long distance trip. At start, drivers usually drive to the major road (such as a motorway) and use it, unless they are close to their destination. If so, they leave the major road and chose as big road as they can. However local authorities in almost all countries provide information about road classes, division prepared by the government cannot be directly utilized to work with the Highway Hierarchies.

This algoritm assumes that when driver is on the certain hierarchy level of the road network, he must not leave it temporally to reach it again after some time. To handle this requirement, an artificial division of the road network into the hierarchy level must be performed.

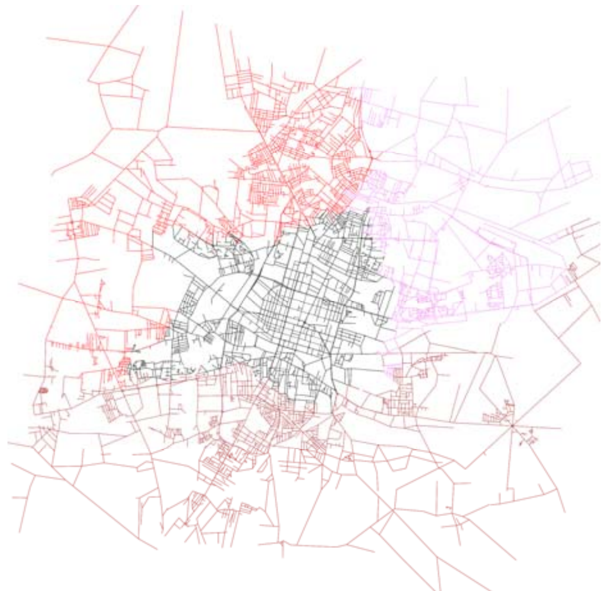

Fig. 1 Example of the division of the Road network into sectors

Method of preparation of such a division given in [9] is quite time consuming. Authors of this work proposed in [10,11] extensions of the algortihm that allows parallel computation of each hierarchy level. For this method the road network must be divided into some number of sectors, where calculations are performed independently. Due to the fact, that separate hierarchical division is made for each sector, assumption of not passing to the lower hierarchy level cannot be fulfilled for the long distance queries. This causes the need to improve the querying algorithm to the new conditions. Examplary division of the road network into sectors is given on Fig. 1.

In the first of the following subsections, an outline for the construction phase of the Highway Hierachies algorithm is given. Second subsection contain a description of the modified querying algorithm. Third section contains details of adaptation of the algorithm for solving dynamic vehicle routing problems.

Highway Hierarchies construction phase

Construction of the Highway Hierarchies graph is an iterative process performed for the whole graph. Algorithm needs to parameters: maximum hierarchy level and size of the neighborhood for each node, denoted as H and N respectively. First step is to find for each node N closest nodes in the sense of Dijkstra's algorithm. After that, for each node partial spanning tree is built. Its construction is stopped, when leaf nodes are not in the neighborhood of the base node descendants. After building the spanning tree, edges that link nodes that are far enough from source and leaf node are promoted to the higher hierarchy level.

When the construction of the current hierarchy level is completed, iteration for next level is only performed on the newly promoted links.

Modified querying algorithm

Parallel Hierarchies assumes that hierarchical division for all of the sectors obtained in the partitioning process is calculated independently. What is more, when hierarchical division is performed on the sectors, instead of the whole graph, hierarchy levels for edges in the sector, can be different to levels of corresponding edges in the input graph. Due to the fact, that in Highway Hierarchies the query algorithm depends on the proper hierarchical division of the graph edges, we had to adapt the algorithm to our method.

In HH algorithm, edges and nodes that are on the highest hierarchy level belongs to the one connected component. In case of parallel division, edges belonging to the highest hierarchy level, make a connected component in each sector.

When both source and target node are placed in the same sector, both search scopes can meet without any modification of the querying algorithm known from HH, as there is only one connected component in the highest hierarchy level for each sector.

Situation is more complicated, when the path between the source and target node crosses the borders of sectors. The idea of the new algorithm is that actual query is split into smaller subqueries, each of which is performed inside one sector. In this case one have to identify border nodes, which are source and a target node for a subquery. In the final step, results of all of the subqueries are merged to find a proper itinerary.

Detailed algorithm of finding the path between nodes s and t is as follows:

1. Let $n = s$. Let $I = \theta$;
2. Add n to I
3. Find the node $b \in B_k$, which is nearest node from the line connecting n and t. Add *b* to I.
4. Let $n = b$
5. If n and *t* are not in the same sector, go to step 2.
6. Add *t* to I
7. Perform subquery for each neighbouring pair of nodes in I.
8. Merge results of all subqueries

List I contains source, target, and border nodes that are going to be traversed in the final result.

Solving dynamic Vehicle Routing Problem

Parallel Hierarchies allows to perform construction of the hierarchical division faster than Highway Hierarchies as computational complexity of the problem is reduced [10]. Independent construction for each sector allows to redefine weights of the road segments belonging to that sector without modification of other parts of the map. Algorithm can be also applied for solving dynamic Vehicle Routing Problem.

Proposed method can be utilized when vehicles need to be attracted or distracted from certain place. This situation happen when i.e. package delivery company needs to collect new orders as fast as possible. The company usually have an information when its clients are located. If such information is encoded in the weights of the road segments, drivers can be routed via streets, where there is a higher possibility for collecting new order.

Distraction can be helpful in case of the road accidents or road closures. Closed road segments are usually deleted from the road network, but one can change weights of the neighboring roads to steer the traffic to other direction.

Method of adaptation of road segments' weights can differ depending on the problem. To prepare new values for the weights of road segments we introduce the term of AD region, which is a set of road segments for which weights are modified in some way. When the same value of the tuning parameter is assigned to the whole AD region, one can use either Eq. 2 or Eq. 3 to obtain adapted value of the weight.

(1) $$w_f = w_b c_{AD}$$

(2) $$w_f = w_b + c_{AD}$$

In Eq. 2 we handle a case, where trip takes c_{AD} times lower than usual, or, in case of taxis, the probability of new order is greater $1/c_{AD}$ times. The second case (Eq. 3), addresses the situation when driver needs to wait some time to drive through the road segment (when $c_{AD} > 0$)

(3) $$w_f = w_b f(n,d)$$

In some cases one cannot use the same value of the tuning parameter for the whole region. We can introduce Eq. 4, where final value of the road segment's weight depends on the value of the function of n - node in the graph and d - distance from the centre of the AD region.

In our research for overlapping AD regions we multiply values c_{AD} coefficient of each region that contains a certain edge. This situation allow us to handle situation when both distraction and attraction is supposed to happen for the edge. One can also take maximum or minimum of the AD tuning parameter values.

Obtained results

We analyzed two situations in the city of Lodz, Poland. At first, depending on the values from traffic counters streets with the highest number of vehicles in the morning rush hours were identified and specified distraction coefficients were applied to prevent drivers from choosing such streets.

In the second case we tried to attract drivers from the package delivery company which are on the route to slightly change their plan in order to respond faster for new transport requests.

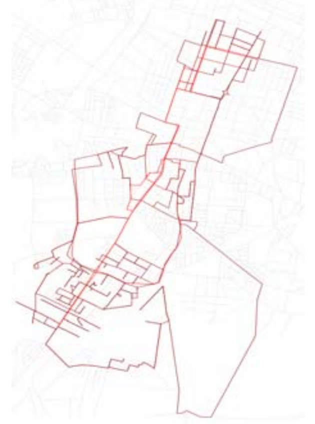
Fig. 2 Strong attraction

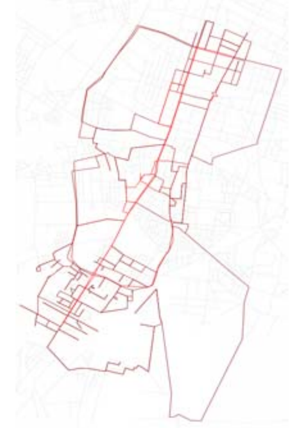
Fig. 3 Weak attraction

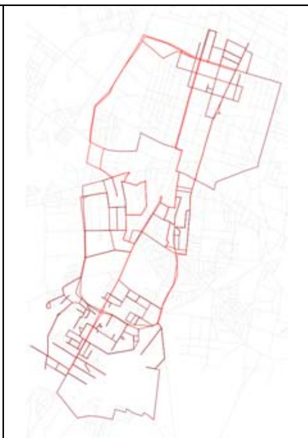
Fig. 4 Weak distraction

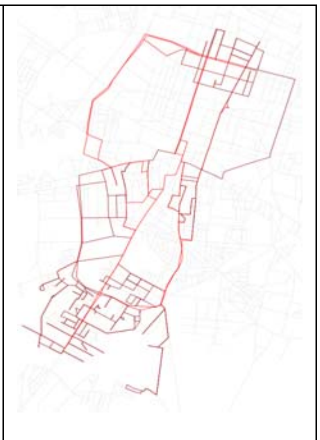
Fig. 5 Strong distraction

Both experiments were performed in the MATsim environment. For visualization we used TrafficVis application.

Differences in the structure of the division

Results for examination of the divided graph structure are gathered in the Table 1. Each row contains the number of road segments on each hierarchy level, depending on the value of the tuning parameter in the algorithm.

Table 1. Results for examination of the divided graph structure

Hierarchy level	Base	Attract (0.1)	Attract (0.5)	Distract (2)	Distract (10)
0	6011	5970	5999	5915	5914
1	2862	2790	2825	2626	2632
2	2086	2017	2033	1955	1997
3	6420	6602	6522	6883	6836

As one can see, differences in the number of edges on certain levels can be up to 9 percent. This shows, that each time new AD regions appear, one have to recalculate the hierarchical division of the road segments in certain sectors.

What is more, number of edges on each level of the hierarchy depends on the direction of the AD tuning parameter. In columns 2 and 3 in the Table 1, values differ hardly any. The same situation is in columns 4 and 5 (for distraction). When AD region is located in the single sector, it only influences hierarchical division in this sector.

Route selection

Optimal route selection results are shown on Fig. 3 to Fig. 6. Drivers start their trip in the bottom of the maps and drive to the top. AD region is placed in the centre of a given map. Major roads are located in the left and central parts of the examined region.

As one can see, when the attraction is very high, drivers that chose the left-side bypass, turns right and drive through the central one. When the attraction is lower, drivers do not resign from the previously chosen route (Fig. 4). When drivers are distracted to drive through the central bypass, most of the traffic appear in the left-side. What is more drivers turns left or right, when they are affected by distraction.

Conclusions

Proposed solution can be applied in different classes of problems. In the first case, drivers were successfully distracted from driving trough the city centre, so that traffic was better distributed to the streets in the same direction.

Our approach for handling dynamic requests from potential customers is based on the idea of sampling but it is not directly associated with the probability. However new routes for drivers are not ‘the best of’, handling new requests costs less in this case.

Acknowledgement

Development of the software for traffic data visualization was supported by European Regional Development Fund, Innovative Economy under grant "Platforma Informatyczna TEWI" (no. POIG.02.03.00-00-028/09)

REFERENCES

[1] Clarke G. and Wright J. W.: Scheduling of Vehicles from a Central Depot to a Number of Delivery Points. Operations Research, 12(4):568-581, 1964.

[2] Gilbert Laporte: The vehicle routing problem: An overview of exact and approximate algorithms. European Journal of Operational Research, 59(3):345-358, June 1992

[3] Yang Jian, Jaillet Patrick, and Mahmassani Hani: Real-time multivehicle truckload pickup and delivery problems. Transportation Science, 38:135-148, 2004

[4] Gendreau M., Guertin F., Potvin J., and Taillard E.: Parallel tabu search for real-time vehicle routing and dispatching. Transportation Science, 33(4):381{390, April 1999

[5] Bent Russell W. and Van Hentenryck P.: Scenario-based planning for partially dynamic vehicle routing with stochastic customers. Operations Research, 52:2004

[6] Piwonska A. Koszelew J.: A new evolutionary algorithm for routes generation with optimal time of realization in public transport network. JACS, 2010

[7] Kilby P., Prosser P., and Shaw P.. Dynamic vrps: A study of scenarios. Technical report, 1998

[8] Hyeong Soo Chang, Givan R., and Chong E.. On-line scheduling via sampling. Artificial Intelligence Planning and Scheduling (AIPS, pages 62-71), 2000

[9] Delling D., Sanders P., Schultes D., and Wagner D.: Highway hierarchies star. In 9th DIMACS Implementation Challenge, 2006

[10] Chomątek Ł. and Poniszewska-Marańda A.: Multi-agent system for parallel road network hierarchization. In ICAISC (2), pages 424-432, 2012

[11] Chomątek Ł.: Multi-agent approach for building highway hierarchies graph. In Information Systems Architecture and Technology. System Analysis Approach to the Design, Control and Decision Support, 2010

***Authors**: mgr inż. Łukasz Chomątek, Politechnika Łódzka, Instytut Informatyki, ul. Wólczańska 215, 90-924 Łódź, E-mail: lukasz.chomatek@p.lodz.pl*