2006 IEEE International Conference on
Systems, Man, and Cybernetics
October 8-11, 2006, Taipei, Taiwan

Adaptive Travel Time Path Selection in Hierarchical Index Road Network

Adisak Sukul, Pattarasinee Bhattarakosol, *Member, IEEE*

Abstract— **It is the truth that spending life on the road is not fun. Therefore, every driver is searching for the "shortest path" for their traveling. Since the real objective is the smallest time frame that the driver spends on the road before arriving at the required destination. Various methods have been proposed to solve the problem of this shortest path under the hierarchical index road network. Unfortunately that none of them has considered the situation of traveling in the congestion traffic mode. This paper presents a solution, called an adaptive travel-time path selection algorithm, to obtain the shortest path where the shortest travel-time has been achieved. The experiment had shown that the selected path obtaining from the proposed algorithm has less time complexity than the previous existing methods.**

Index terms—**Spatial database, Geographic Information System GIS, shortest path algorithms, hierarchical data, database index**

I. Introduction

SOLVING travel-time path selection is significant interest for application that work in spatial data network. Drivers always concern with their travel-time more than concerning about traveling distances. Therefore, the meaning of the shortest-path is referred to the smallest time count spending from starting point to the required destination.

Various researches had considered the shortest-path and nearest neighbor queries in geo-positioning e.g., road network, without the situation of the network congestion. Previous work results in techniques to compute Euclidean space [2] have been proposed to compute nearest neighbor queries in spatial networks. These methods extend nearest neighbor queries by considering spatial network distance. By [1] also considers the static travel-time in road network and geo-position locator concerning on path selection of spatial network quires. However, these existing techniques consider the weighted cost of paths using static information of path distance, or immediate travel-time. Thus, it is not enough to perform a future traveling plan. Therefore, the guiding system needs to keep record of travel-time submitted by users at a data center and retrieves the time estimation information for guiding the users' traveling plan.

This new design hierarchical index data on road network and path selection algorithms are made use of recording real travel-time data set that reflects by a mobile unit in the high congestion road network. The real travel-time data set is to participate in shortest time path calculation that provides much accurate results than existing algorithms in case of highly congestion network, e.g., in urban road or in the most busy city in the world. The proposed algorithm can also be applied to implement in many applications e.g., path selection of travel planning on road network, logistic planning and mobile agent traveling in high congestion network.

The proliferation of wireless and cellular communication (e.g., GPRS and 802.11x) and geo-position locator system (e.g., GPS), have created environment that *mobile unit* can remotely exchange information with a *data center* that play role in collecting and categorized data set from a mobile unit.

The paper contribution is on two levels. First, the paper describes a general, data model for hierarchical index road network (HIRN). A hierarchical index road network is indexed on the top of a digital map of the road network, consisting of recorded travel-time of real traveled data submitted from mobile unit, separated in time slot.

Second, the paper proposed the adaptive travel-time path selection algorithm on hierarchical indexed road network that performs faster path selection in term of travel-time than the existing shortest path or nearest neighbor algorithms.

The rest of paper is organized as follows. The related work is described in Section II. Section III defines the hierarchical index road network and introduce the adaptive travel-time path selection algorithms. The experimental validation of our design is presented in Section IV. Finally, the conclusions and future work are presented in Section V.

II. Related Work

This section review previous works related to the Nearest Neighbor query (Section A.), inter-vehicle communication (Section B), and Distributed Shortest Path Algorithm for Hierarchically Clustered Data Networks (Section C).

A. Nearest Neighbor query

The R-tree algorithm and its extensions are very popular index structures for spatial query processing in the Euclidean space due to their efficiency and simplicity. A best-first NN algorithm [7], proposed by G´ısli et al., keeps a heap with the entries of the nodes visited and the algorithm always expands the first entry in the heap. The best-first NN algorithm is

Manuscript received March 15, 2006.
A. Sukul is with the Department of Mathematic, Faculty of Science, Chulalongkorn University, Bangkok, 10330 Thailand (e-mail: Adisak.Suk@Student.chula.ac.th).
P. Bhattarakosol is with the Department of Mathematic, Faculty of Science, Chulalongkorn University, Bangkok, 10330 Thailand (e-mail: Bpattara@sc.chula.ac.th).

optimal, because it visits only the necessary nodes for obtaining nearest neighbors.

B. Inter-vehicle communication

Inter-vehicle communication (IVC) enables a vehicle (and its driver) to communicate with other vehicles (and their drivers) exchanging real time information, such as road conditions, traffic speeds, and weather hazards. Benefiting from the power capacities of vehicles, the nodes of these networks can have a virtually unlimited lifetime. The design of communication protocols for IVC is very challenging due to the variety of application requirements and the tight coupling between an application and its supporting protocols [11]. Therefore, there are several very recent research projects (such as FleetNet and CarTALK 2000) investigating next generation IVC protocols and technologies.

C. Distributed Shortest Path Algorithm for Hierarchically Clustered Data Networks

This is new efficient shortest path algorithms to solve single origin shortest path problems (SOSP problems) and multiple origins shortest path problems (MOSP problems) for a class of hierarchically clustered data networks with n nodes. Under the SOSP problems, the distributed version of the SOSP algorithm has the time complexity of $O(\log(n))$ which is less than the time complexity of $O(\log^2(n))$ achieved by the best existing algorithm.

On the other hand, the MOSP algorithm minimizes the needed computation resources, which include computation processors and communication links, for each shortest path computation. So, the massive parallelization can be achieved. The parallel time complexity of the MOSP algorithm is $O(m\log(n))$,which is much less than the time complexity of $(M\log^2(n))$ of the best existing algorithm. Here, M is the number of the shortest path to be computed and m is a positive number related to the network situations and m is usually much smaller than M. Moreover, the value of m is, almost, a constant when the network size increases.

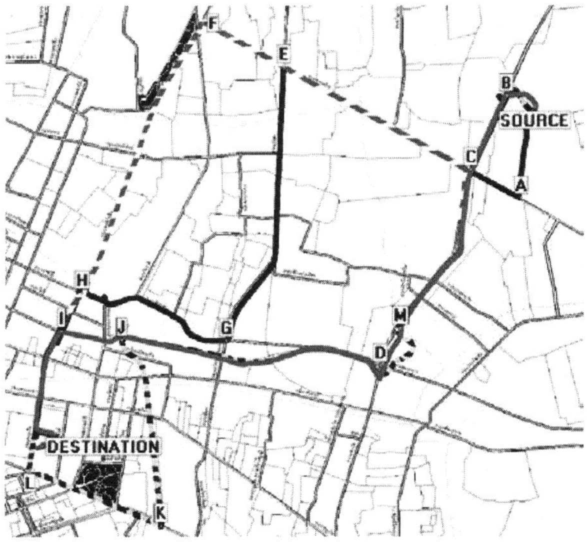

Fig. 1. The 4 alternative paths from Bangkok city road network.

TABLE I
TRAVEL INFORMATION COLLECTED FORM FIG. 1.

Path	Set of Vertices	Distance (Km.)	Travel time (Hrs.)	Average Speed (Km/H)
Path 1 (Gray line)	{Source, B, C, M, D, J, I, Destination}	16.837	1:01:02	16.547
Path 2 (Black line)	{Source, A, C, E, G, H, I, Destination}	18.103	1:08:05	15.950
Path 3 (Gray/White line)	{Source, B, C, E, F, H, I, Destination}	19.615	0:36:43	32.053
Path 4 (Gray/Black line)	{Source, B, C, M, D, J, K, L, Destination}	21.293	0:47:08	27.106

III. STATE PROBLEM

The geo-position locator system and digital map are widely used to combine with the wireless communication system. It enables many navigation services extended from a mobile unit locator service; information can be exchanged between mobile unit and data center.

The one classical problem was selecting the best path to travel from one point to another by least travel-time as possible. This is the significant interest under the problem of individual travel and business logistic planning. In order to solve this problem, the required preliminary information was a digital map of possible transportation path (e.g. road map for land transportation, marine/watercourse map for waterway transportation). Then the calculations have been performed to find the shortest-path [6-8] from the source to the destination location according to the digital map, as the view directed weight graph. From the existing method, the weight of an edge connects between a pair of vertices in the graph from the digital map was an actual distance. The result of this method is the shortest-distance rather then the fastest time. Thus, position-aware shortest-path algorithm can increase the efficiency. A resent method [1] has made conversion from the travel-distance to the travel-time using speed limited of each transportation path or actual travel-time of an individual mobile unit that submitted to the data center.

In the real situation, especially in a high traffic congestion environment, various factors can influence to the travel-time to the destination (e.g., congestion, driving behavior, vehicle limitation and special congestion event). Unfortunately that the existing methods do not covered this problem.

Considering Fig. 1, the collecting Information from a real road network of Bangkok City, shows that there are 4 alternative paths from the source to the destination point. Each path has difference distances and details of distances, travel-time and average speed, presented in Table1.

From Table1, it was cleared that the travel-time was not directly relevant to the distance. Path 1 was the shortest-path

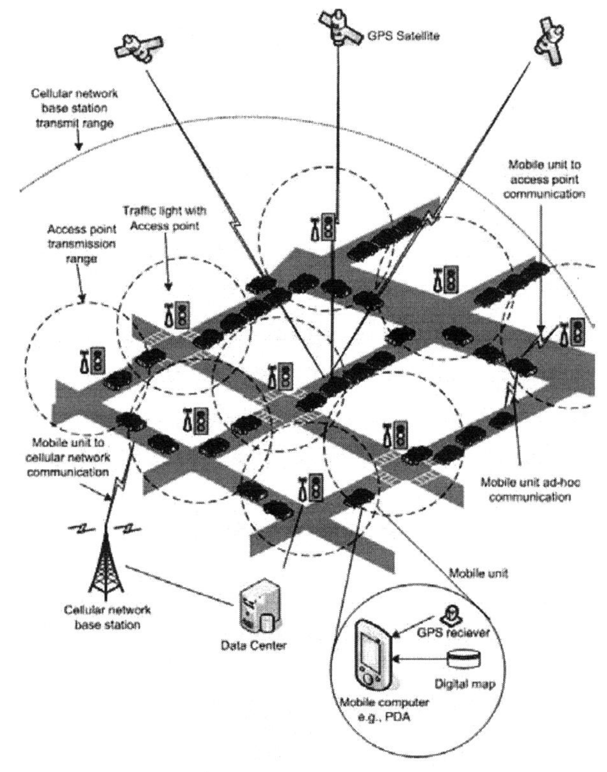

Fig. 2. The system infrastructure.

in term of distance. On the other hand, the shortest-travel-time is what drivers expected, is Path3 because the mobile unit can travel with a higher speed thru Path3 due to less congestion in the road network. Thus, in the real situation, the congestion can made a large impact on shortest-path selection in term of the travel-time. Beyond that, period of time during a day and the days during a week can make a big difference on congestion of each road (e.g., in weekday rush hours, the road approach downtown will be very busy. In other hand, the same road will almost empty by late of night time.)

IV. Propose Method

A. System Design

We outline our system architecture in this section and propose a design of hierarchical index on road network (HIRN) that collects and manages information of real travel time from the mobile unit member that can represent high accuracy of high congestion network. We also develop an adaptive travel time path selection algorithms (ATPS) on hierarchical index road network, which can perform faster path selection in term of travel time than existing shortest path or nearest neighbor algorithms. The ATPS algorithms will discuss in the next section.

The system infrastructures are explained in 1). Next, hierarchical index on road network (HIRN) are discussed in 2). Congestion Information collection and exchange with mobile unit are explained in 3).

1) System infrastructure: Fig. 2. illustrates the system infrastructure of the proposed design. The design considers a *mobile unit* with a mobile computer (e. g., PDA) without limitation of power, equipped with GPS receiver for obtaining a stream of location information and also a standard vector digital map database that maintains the road network data. In this research, the researchers are not limit the vector digital map on mobile unit from the same providers. A group of members can be formed by most navigation system where all users own mobile equipment that reach the requirement of the proposed solution (mobile computer, a GPS receiver and a digital map). This will allow most users on difference navigation system equipment providers, to be able to make use of ours application. Then the mobile unit can automatically submitted their travel-information and gain advantages from the system by receiving much accurate shortest travel-time path. In additional, a simpler output from this system can be displayed on the outdoor traffic information board, on digital map displayed thru web site (e.g., [6]) and also available for other system thru web service protocol. Then other road network users who don't have mobile unit equipments, still can obtain some benefit from the proposed system.

The *wireless communication* between a mobile unit and the data center is not restricted; long length and small response time was preferred. The 802.11x wireless network are considerably suitable to the considered system. In an urban area, the wireless access point could be implemented with a traffic light or a traffic information display board so will cover a large amount of users in a highly congestion road network.

The multi-hop wireless network was not considered in this case, due to uncertainty of medium-act mobile unit availability. Wireless cellular networks (e.g., GPRS) are needed when another short length wireless network is unavailable.

The *data center* is a host of the proposed system, receiving and organizing all location information sending by a mobile unit. This data center also replies paths and several alternative paths with time estimation of each requested path (source and destination) by the mobile unit. In the data center, it contains a standard digital road map and indexed by Hierarchical index on the road network (HIRN). The assumption is that the data center always available on the network and has no limitation of its storage space.

2) Hierarchical index on road network (HIRN): are index on digital road map, Fig. 3. show HIRN map index level and Table2 explain data representation and sample values of HIRN. From simple definition of road network represented by directed weight graph, vertices are representing a junction on road network and edges are representing a road with distance as a weight cost.

By having hierarchical structured index led two advantages to systems. First, system can keep multiple information of each road and also each sub road path. Second, led query algorithms (ATPS) perform faster. The main information that

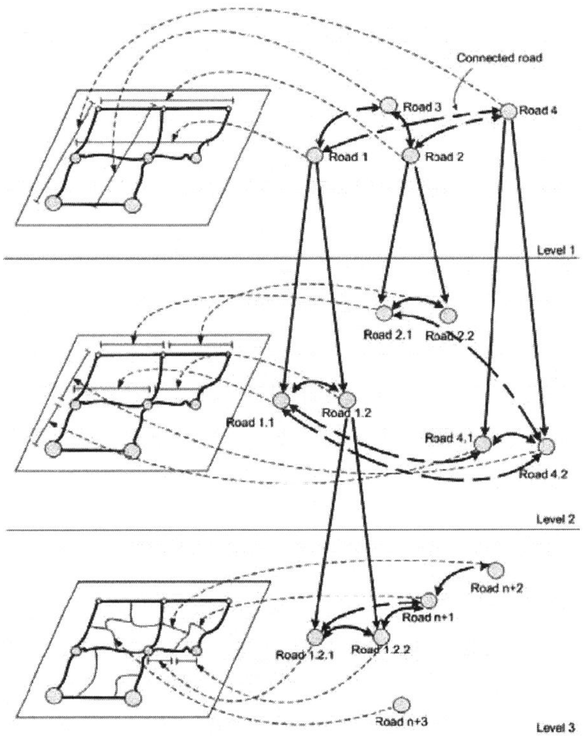

Fig. 3. Hierarchical index on road network (HIRN), map index level.

TABLE II
HIERARCHICAL INDEX ON ROAD NETWORK (HIRN)

Path ID	Property	Sample Values
Road1	Road type	Main road, 2 way
	Vertices set	{A, D, C, B}
	Distance (kilo meters)	{21.4}
	Travel time table (minutes)	{2, 2, 2, 4, 6, 10, 11, 10, .. , T} (48 * 7 time slot per Travel time table, separate by 48 half of hours * 7 days of week) sum up from lower level
	Travel time table in Reverse direction (minutes)	{4, 4, 3, 4, 6, 10, 11, 10, .. , T} (48 * 7 time slot per Travel time table, separate by 48 half of hours * 7 days of week) sum up from lower level
	parent	Root
	Child	{Road1.1(A, D), Road1.2(D, C), Road1.3(C, B)}
	Connected road	Road 3, Road 4
Road1.1	Road type	Main road, 2 way
	Vertices set	{A, B}
	Distance (kilo meters)	{11.2}
	Travel time table (minutes)	{0.7, 0.7, 0.8, 1, 1, 2, 4, 5, .. , T} Travel time table, sum up from lower level.
	Travel time table in Reverse direction (minutes)	{0.8, 0.8, 0.9, 1, 1, 2, 4, 4, .. , T} Travel time table, sum up from lower level.
	parent	Road1
	child	{Road1.1.1(A, D), Road1.2(D, C), Road1.3(C, B)}
	Connected road	Road 1.2, Road 3.1, Road 3.2, Road 4.1, Road 4.2

Data representation and sample values of Hierarchical index on road network (HIRN). Referred from Fig. 3.

being investigated was congestion information which can calculate from average of travel time divide by actual distance (C = T/D). The following will be general description of initial and maintaining process of HIRN. Note that all process was running on data center.

The initial processes are

--First, analyze the digital map in data center; categorize a main road, medium road and small road.

--Second, generate index node of each level; node are represent road or sub road (in higher level), connected road will be indicated.

The maintaining process by

--First, when mobile unit submit new information of their travel speed, HIRN will update the travel time table at highest level of index (smallest path of road) and in particular time slot (slot that contain information of same day and time)

--Second, sum time value of child node and update to ancestors node

-- Third, when a digital map has been updated, HIRN required repeating an initial process.

3) Congestion Information collection and exchange with mobile unit: this section will explain about how mobile unit are exchange information with data center. The mobile unit are usually PDA equipped with GPS receiver and digital map, implemented on vehicle and covered by wireless network thru access point or thru cellular network. The following will be situation of information exchange between mobile unit and data center. We assume that data center is always available on the network.

--First, initial state of mobile unit, user turn on their devices, acquiring network connection and GPS locator.

--Second, when mobile unit ready and moving, their keep sending summarize of location information to data center.

--Third, when user want perform a quires for shortest travel time to destination, The mobile unit will submit request message along with source and destination location. Data center will reply paths and several alternative paths with time estimation of each path (source and destination) back to mobile unit.

B. Algorithms

We outline our propose algorithms in this section. The adaptive travel time path selection algorithms (ATPS) on hierarchical index road network, which can perform faster path selection in term of travel time than existing shortest path or nearest neighbor algorithms.

In travel time network shortest-path (TTN shortest-path), weight cost of graph are considered in term of travel time. More than that, all road junction are labeled by coordinate. Then in algorithms, weight cost of next vertices are (time weight + (average time on that particular path * coordination distance to destination)) ($T + T_{avg}$ * Coordinate Distance). This method result to provide position-aware shortest-path.

The main program of adaptive travel time path selection algorithms (ATPS) can be describe as following.

1) *Mobile unit passed all initial process.*
2) *Mobile unit request the shortest-time path to data center, ATPS (source, destination) and time period of travel (normally is the present time, if this use in future travel plan, use time that mobile unit will actual travel)*
3) *Data center return path back to mobile unit (set of vertices) and travel time estimation of path.*
4) *While there still have alternative path, data center repeat return the next path and travel time estimation of them. This alternative path return will occurred when the travel time estimation of the best path + k threshold constant >= alternative path ($T_{p1} + k >= T_{p2}$; set of return path = {p1, p2})*
5) *Mobile unit will displayed all return path and indicate time estimation of each path for user decision.*

The following are explain the ATPS (x, y) function. Lets Q be the set of return path.

1) *Receive coordination of source and destination from main program; snap the coordinate on road network with digital map in data center.*
2) *If source or destination are not on main road then*
3) *Finding TTN shortest-path of source and destination to main road at M-level index (most level). Then add vertices in to Q.*
4) *Repeat TTN shortest-path until both source and destination have path to main road with M-1 level (until one of vertices in Q be a member of Level 1 index).*
5) *If vertices in Q are not connected as a path. Then finding TTN shortest-path between members of Q at 1st level index (finding medium path with main road, due to assumption that most shortest-time path are usually passing the main road as much as possible).*
6) *Repeat until complete path are in Q. sum travel time values from table of each vertices (in particular time slot)*
7) *Repeat finding TTN shortest-path between members of Q at I + 1 level index, until sum of travel time are equal or grater that path in previous shortest-path (after we have shortest-path with mostly on main road, then we performs a comparison on smaller road)*
8) *If found new sub path on higher detail index level, then replace those previous vertices with newly vertices found.(If some smaller road can provide smaller amount of travel time*

TABLE III
COMPARISON OF ALGORITHMS PERFORM

	ATPS on HIRN (our algorithms)	Dijkstra's algorithms	NN Queries in Travel Time
Number of computation	53	454	151
Accuracy of estimated travel time	92%	65%	84%
Space usage	most	Less	medium

Comparison of case study, base on information from standard Bangkok city road map, Fig. 1. and Table 1.

9) *Repeat from step 1) until travel time estimation of the best path + k threshold constant >= alternative path (Tp1 + k >= Tp2;) then add new set of vertices on Q2. (This method is to find possible alternative path.)*
10) *Return set of vertices and time estimated (Q, T) and (Q2..Qn, T2..Tn) if alternative path are present.*

From step 5. of ATPS (x, y) function above, finding medium path with main road, due to assumption that most shortest-time path are usually passing the main road as much as possible. This are one of factor that the adaptive travel time path selection algorithms (ATPS) performs less number of running times than existing method.

V. CASE STUDY

From section III. State Problem, are display the problem of low accuracy and time complexity, existing in finding shortest-travel time path on road network, especially in high traffic congestion environment. With our algorithms, the adaptive travel time path selection algorithms (ATPS) and Hierarchical index on road network (HIRN) system design, present that can increase accuracy and reduce time complexity of these problems.

From situation of Fig. 1. and Table 1., the followings case study of solving problem by our propose system and algorithms, comparison will displayed in Table 3. with sample on existing method.

The standard Bangkok road map [6] that used in this case study are consist of 1,250 vertices (V) and 654 edge (E), these graph are represent of actually only 148 (Rmain) main road. This case study was made by input of same source and destination on Fig. 1.

VI. CONCLUSION

Solving shortest-travel time path on road network problem, of existing method are face with low accuracy and time complexity problems, especially in high traffic congestion environment. With our algorithms, the adaptive travel time path selection algorithms (ATPS) and Hierarchical index on road network (HIRN) system design, present that can increase accuracy and reduce time complexity of these problems. More storage space usage are only disadvantage of our propose.

Our system are also presented that simple implementation are possible, Group of user member can be formed by most navigation system user where as user own mobile equipment that meet our requirement (mobile computer, GPS receiver and digital map). This will allow most user of difference navigation system equipment provider get advantage from system by receiving much more accuracy shortest travel time path.

REFERENCES

[1] W. Ku, R. Zimmermann, H. Wang, and C. Wan, "Adaptive Nearest Neighbor Queries in Travel Time Network," In *Conf 2005 ACM GIS'05*, Bremen, Germany, November 4-5, 2005, pp. 210–219.

[2] Nick Roussopoulos, Stephen Kelley, and Fr´ed´eric Vincent, "Nearest Neighbor Queries in Road Networks," In *Conf 2003 ACM GIS' 03*, New Orleans, Louisiana, November 7-8, 2003.

[3] S. Srikritsanapol. (2006, Feb 10). GPS Knowledge Base [Online]. Available: http://www.ThaiMTB.com

[4] Department of Communication, Royal Thai Police. (2005, May 10). Bangkok city digital map with traffic status (2nd ed.) [Online]. Available: http://www.trafficbkk.com

[5] J. K. Antonio, G. Huang and W. K. Tsai, "A fast distributed shortest path algorithm for a class of hierarchically clustered data network," IEEE Transactions on Computers, Vol. 41, N0.6, pp.710-724,1992.

[6] G. Huang and S. Zhu, "A New Distributed Shortest Path Algorithm for Hierarchically Clustered Data Network," In *Proc 1995 American Control Conference*, Seattle, Washington, June, 1995, pp. 2031–2035.

[7] E. W. Dijkstra, "A note on two problems in connexion with graphs,'' Numerical Mathematics, Vol.1, pp.269-271,1959.

[8] E. Bellman, "On a Routing Problem," Quaffefly of Applied Mathematics. 16, pp. 87-90, 1958.

[9] Jacob, R., M.V. Marathe, and K. Nagel. "A Computational Study of Routing Algorithms for Realistic Transportation Networks," 2 nd Workshop on Algorithmic Engineering, Saarbrucken, Germany, August 1998, Los Alamos National Laboratory report LA-UR-98-2249 (May 1998).

[10] E. Kaufman, J. Lee and R. L. Smith, "Anticipatory Traffic Modeling and Route Guidance in Intelligent Vehicle-Highway Systems," lVHS Technical Report-90-2, University of Michigan, Feb., 1990.

[11] L. Fu and L. L. Rilett, "Estimation of Travel Time Distribution Parameters In a Dynamic and Stochastic Network, Working Paper, University of Alberta, 1995, unpublished

[12] R. Hall "The Fastest Path Through a Network with Random Time-Dependent Travel Time, " Transportation Science. Vol. 20, No. 3, pp. 182-,188, 19910.