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RESEARCH ARTICLE

The weighted shortest path search based on multi-agents in mobile GIS management services

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ABSTRACT

In this paper we focus on the mobile GIS management system based on multi-agents, and wider range of client devices with J2ME-MIDP kernel are supported in it. A kit (Map Database Manager) is developed and described in detail. The kit can convert GIS data of commercial formats such as ArcGIS and Mapinfo into Geospatial data in GML, and provide Geospatial data for handheld devices freely without commercial plug-in software. A peer to peer multi-agents mechanism on mobile GIS services is the main subject of this paper. According to user's requirement and known buffer area radius on map, agent can define the factors to calculate the optimal path from one node to target node in a map, which considers not only the length of the road but also traffic flow, road cost, and other factors. We use the integrated cost to re-define the road path weights, and select the optimal path among the road based on the minimum weight. The actual experimental results shown that in the quantified traffic flow and road condition, from node to other target nodes, we can get an optimal path on map, which satisfies the condition mostly. The results can greatly assist the searching of the optimal path in GIS services.

KEYWORDS
handheld device; mobile GIS; multi-agents; optimal path search

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1. INTRODUCTION

As mobile computing is more and more widespread, mobility support for handheld devices becomes very important. Mobility management for wireless network is a promising technology that provides the seamless mobile communications. Here we focus on the Mobile Geographic Information Systems (Mobile GIS) management system based on multi-agents. The introduction of GIS [1] has changed the way we use, manipulate, access, and understand geographical and spatial information. Current systems can provide the operators with location, map information, distance, and so on, and are widely used by business, government, and individuals. Over the years, through augmentation of functionality, these systems grew in scope and became powerful tools for operational planning and decision making.

Real-time and seamless access and usage of spatial information are a natural and necessary extension to traditional usage of maps and geographic information systems. In recent years we have seen exponential growth in the amounts of data that is being collected and stored (currently at a rate of 400 GB/s). Most data are tagged with geographical location information for future references. In addition to data availability, we are witnessing a significant growth in the mobility of society which leads to greater dependency on spatial data and spatial data manipulation (as our mobility grows, the world is becoming "smaller"). Tools such as Google Earth and Mapquest are commonly used. The demand for spatially referenced services is increasing and will continue to do so in the future.

Mobile devices in the form of portable telephones, pagers, PDA, and notebook computers are now commonplace. All these devices can be distinguished from each other by functionality, physics characteristics, and destination. But user with different characteristics may be interested in different geographical information presented on a page and may use different navigational style and different devices such as PDA, Mobile Phone, and PC browser.

The base geographical data is large and complex, which is unfit for transfer directly between wireless network and mobile devices, because of the poor width of wireless communication and limited capabilities of mobile devices. Most of Pocket PC and mobile phone can interpret the grid map data and pictures such as jpeg, png, and gif exactly, but cannot deal with and display on vector data very well. Generally, the displaying, inquiring, and updating of geographical data in mobile devices are all depended on GIS server. It must be an application bottleneck in the case of more and more users and GIS operating at the same time. On the other hand, not all geographical data updating and using are interested by other people. Therefore, instead of adding up all new or updating geo-data to original geographical data, we can deal with those data peer to peer.

Based on geographical data, Shortest Path Search is to select the best path from known node to target nodes that meet the conditions on the map in the known circumstances and the radius of buffer area, according to the user's request. The shortest path and distance between vertices in a spatial network is the most important services in mobile GIS. However, pre-computing the shortest path and distance between all pairs of vertices in a spatial network is perceived to be prohibitively expensive, the efficient shortest path computation in the varying speed conditions on a large scale spatial network is an essential problem in modern navigation systems.

In our previous work, agent-oriented computing has been used to increase the effectiveness of users in complex application domains of GPS/GIS applications in mobile devices such as PDA, Pocket PC phone, smart phone, and notebook, which utilize wireless link technology and WindowsCE OS [2–4]. We provide the mobile GIS mechanism based on agents, which can distinguish the specific device and user's profile, deal to different geographic data and assist the inquiry of the optimal path in GIS services. Peer to peer agents [5] can act as intelligent aids in advanced mobile services for users' benefit, and artificial intelligence techniques can be applied in many situations in order to turn PDAs into Intelligent Personal Digital Assistants (IPDAs).

In this paper, our system incorporates many technologies and research areas, e.g., agent technologies, the location based services, GIS data integration, context aware computing, and web GIS. We provide only an overview of technologies and researches which are most important in the real system. The main contributions are as follows.

Firstly, Mobile GIS System and Multi Agents Subsystem are designed.

A mobile user-centric ubiquitous environment where users can access, use, and manipulate spatial data explicitly as well as implicitly in their mobile devices is created. Users' interactions with or within the system are facilitated through agents. An intelligent agent is situated in an environment that consists of users, geographic data, networks, data sources, other agents, and distributed geographic services, all of which are ready to serve the user by taking the user's needs and state into account. Thus, the objective of our work on Mobile GIS System and Multi Agents Subsystem is to develop a framework which permits the proliferation of geographic data through seamless connection and collaboration between users, and provides the interaction with distributed geographic services or data centers.

Secondly, Map Database Manager is implemented to integrate different Geospatial data.

One important aspect of a multi-tier spatial system is the accessibility of spatial data. The distributed data collections may be created in different data formats. Therefore, the data integration is an important issue in system. Another work in our system is to enable mobile users to access maps from mobile devices in real-time where the maps are potentially stored in different databases and are encoded in different formats. In our system, Map DB Manager is designed to carry on this work. It is a kit which can convert GIS data of various formats (such as ArcGIS and Mapinfo) into GML document. Geospatial data in GML is the basic GIS data format in our system, it is a standard GIS data format that can be applied in other systems.

Thirdly, the service is implemented based on Optimal Path Search strategy.

According to the user's requirement and known buffer area radius on map, we defined the factors to calculate the optimal path from one node to the target node in a map, which considers not only the length of the road but also traffic flow, road cost, and other factors. We use the integrated cost to re-define the road path weights, and then select the optimal path among the road based on the minimum weight. The actual experimental results shown that based on the quantified traffic flow and road condition, from node to other target nodes, we can get an optimal path on map, which satisfies the condition mostly. The results can greatly assist the inquiry of the optimal path in GIS services.

The rest of the paper is organized as follows. Section 2 mentions some related works. Section 3 formally describes the system framework. In Section 4, we provide a manager to deal with GIS data. In Section 5, based on Time Transport Network, the strategy concerning with the Optimal Path Search in our system is presented. In Section 6, based on the quantified traffic flow and road condition, the actual experimental results are shown and analyzed. Finally, Section 7 concludes the paper.

2. RELATED WORKS

Except for the above relevant works in Section 1, recently, there are some other relevant works as follows.

2.1. Distributed data access

Data accessibility is important to develop a multi-tier system that is based on spatial data. Large amounts of spatial data are collected worldwide [6]. In order to create a lot of data formats, the data collections need to be distributed. To alleviate this problem, the Open Geospatial Consortium (OGC) has established standards for data retrieval [7], such as Simple Features CORBA and Simple Feature Access 1. Standards provide an excellent way to retrieve data from a variety of data sources. Other standards established by OGC enable spatial data to be transferred easily between distributed objects. During establishing the standard, different models are used to interoperate and access data. A discussion paper [8] is one of the models developed by OGC with distributed data sources and services that can be available in a single client application. Different encoding techniques are used to retrieve data, such as GML, the geography markup language. XML is also being widely used as a tool to interoperate spatial data [9,10]. Data integration is very important in systems which provide ubiquitous services. The GiMoDig project [11] can be used to process data integration/harmonization for ubiquitous GIS users. The objective of the project is to enable mobile users to download European countries' maps from mobile devices in real time which are potentially stored in different databases and encoded in different formats. Issues related to the small-display cartography are investigated, i.e., with different cartographic visualizations, the degree of satisfying users' requirements is depended on the specific characteristics of mobile devices with small displays. By developing a global schema, thematic integration has been come true, while the usage of a common, EUREF-based co-ordinate system supports seamless geometric integration. Also, XML is used to transfer vector-formatted spatial data in the Web [12].

2.2. Spatial networks

A framework is described in this paper that enables spatial queries be efficiently responded on a transportation network. To make the discussion more general, a spatial network is introduced, which is an extension to a network model. Classically, networks are modeled as a graph $G\ (V;\ E)$, where V represents the set of vertices (or nodes) and E represents the set of edges (or arcs) of the network. The set E represents the connectivity information of the graph. A weighted graph is particularly interesting, where a weight is associated with each edge. Additional spatial components of a spatial network are related to the elements (vertices and, or edges) of the graph.

An example of a spatial network is a road network [13]. A road network can be viewed as a weighted graph $G\ (V;\ E)$. For example, each vertex represents a road intersection, and each edge represents a road segment. The spatial position of each vertex with respect to a reference coordinate system is also given, usually in terms of geographical coordinates (i.e., latitude and longitude). Moreover, the weight of an edge represents the length of the associated road segment (or alternatively, the time required to travel the road segment) [12].

2.3. Transportation networks

Recently, there are more and more complex spatial-temporal problems in GIS. To solve these problems, time is regarded as an important component in GIS data models [14]. However, time is not examined much as an integral part of GIS within more than 25 years. In all the solutions on static shortest path described in previous section, time is not considered in the process of solving the problem. As there is only one solution on the problem of finding the optimal route between two nodes based on the cost of distance, if you want to obtain an optimal route based on travel time of each link to change time continuously, a wrong answer will be obtained using the aforementioned static solutions [13].

The links' weights of a network change with time which is defined as Dynamic Network. One kind of networks that have dynamic features is transportation network which is more complex than static network in solving the optimal path problem. Travel time of each link is the most important parameter in transportation networks, which is a function of traffic necessary component for solving spatial problems. Therefore, new problems will be raised with congestion. Since traffic conditions changes continuously with time, travel times will change continuously. Hence, it is important to consider the time as a parameter for finding the optimal path in dynamic networks.

Shortest path problem in dynamic networks has been studies by many researchers [15]. Generally, the optimal path algorithms in dynamic state can be categorized into two classes [16]:

(1) Time-dependent shortest path problem, where network characteristics will change with time in a predictable fashion. In this type, each link has a predictable function of travel time with respect to time.
(2) Recalculation of optimal path due to consecutive, instantaneous, and unpredictable changes in network data. Current methods solve this issue with re-optimization of a set of closely-related static shortest path problems.

2.4. Optimal path problem

In the GIS network model, the geographical feature has always been abstracted from chain nodes and other targets while connectivity is concerned. Network data model will be organized as a graph and one node in it can contact with others.

Optimal Path Search is to select the best path from known point to target nodes that match the conditions on the map in the known circumstances and the radius of buffer area, according to the user's request. It is a summary of the shortest-path problem where the cost measure (in particular, the travel time) to cross a road segments changes with time [17–22]. Decision support module in many cases is used to the optimum path search [23]. For example, during the oil crisis of the value-added services, users may have several options on filling stations. Every gas station may have more than one path to reach; however, which one is the best one for them to go to a gas station? This involves in searching for the best path problem, for example, the value-added services and navigation services. There are multiple paths from one city to another city. However, which path is best is also a problem of the search on the optimal path.

An algorithm to integrate spatial and connect information has been proposed by Huang *et al.* [24]. Thematic spatial constraints are utilized to restrict permitted paths in their approach. However, it is inapplicable in general query processing (e.g., nearest neighbor query). Shahabi *et al.* [25] proposed an approach to perform nearest neighbor queries in road network by transforming the problem to high dimensional space. However, these solutions only extend nearest neighbor queries into the spatial network space without considering traffic conditions. As an extension of NN queries in the Euclidean space, Papadias *et al.* [5] proposed an Incremental Euclidean Restriction (IER) algorithm to solve the problem of finding nearest neighbors in spatial network databases [12].

In our work, we defined the factors to calculate the optimal path from one node to the target node in a map, which considers not only the length of the road but also traffic flow, road cost, and other factors. We use the integrated cost to re-define the road path weights, and then select the optimal path among the road based on the minimum weight, which satisfies the condition mostly. The results can greatly assist the inquiry of the optimal path in GIS services.

3. SYSTEM FRAMEWORK

3.1. Framework of system

In this paper, a mobile GIS system based on peer to peer agents is performed (Figure 1). GPS/GIS applications, such as traveling and geographical information querying, are applied in handheld devices in the system. The use of multi-agents can implement the distributed GIS and overcome the bottle-neck of CPU and bandwidth. Cellular mobile phones and PDAs with J2ME platform and MIDP 2.0 are considered in our system.

J2ME is an open and general API that is platform-independent of hardware and operating system, which permits the development of new challenging services in the wireless world. Mobile Information Device Profile (MIDP) defines an application model to allow the limited resources of the device to be shared by multiple MIDP applications, or MIDlets. It's a minimal kernel to manage the needed mobile phone memory, and provides at least one schedulable entity to run the JVM.

Handheld devices can be distinguished from each other by functionality, physics characteristics, and destination. It is very difficult to categorize mobile devices because their features vary a lot. User with different characteristics

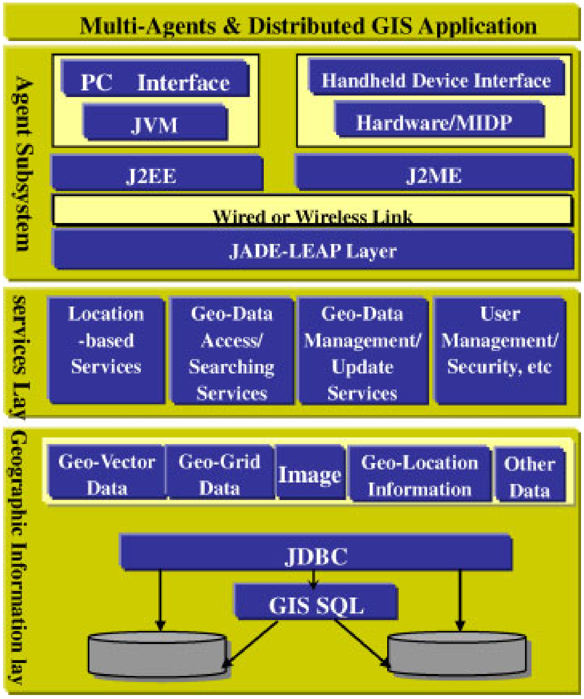

Figure 1. Framework of system.

may be interested in different geographical information presented on a page and may use different navigational style and different devices such as PDA and mobile phones. Therefore, more complicated and wider context should be considered for the delivery of information. Network, protocols, multimedia information type, and other services of varying client devices are quite different, which need a flexible and steady mechanism to meet the challenge.

Based on limited presentation capabilities and operating systems of different mobile devices, different services are supplied to them. Most of Pocket PC and mobile phone can interpret the grid map data and pictures such as jpeg, png, and gif exactly, but cannot deal with and display on vector data very well. Generally, mobile services include map displaying, information inquiring and updating, information communication, and so on.

In this paper, we provide a mobile GIS application system based on multi-agents mechanism.

3.2. Multi-agents subsystem

3.2.1. Multi-agents platform.

Agents are to provide a basic technology for running an aid technology in Java enabled devices, with sufficient resources and connecting to a mobile network.

We use JADE [26] as an agent platform that implements the basic services and infrastructure of a distributed multi-agent application such as peer to peer message transport, parsing, and scheduling of multiple agent tasks. It is extremely light-weight, ported to J2ME-CLDC-MIDP2.0.

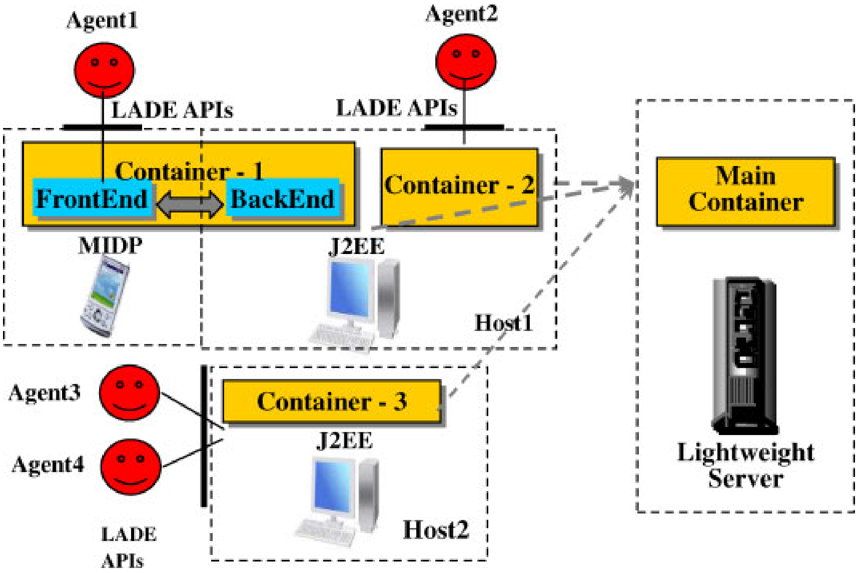

Figure 2. Architecture of multi-agents subsystem.

In order to be deployed on MIDP devices, JADE-LEAP for MIDP is configured as the MIDlet suite.

A JADE-based application is composed of an active components collection called agents. Each agent is a peer since it can communicate in a bi-directional way with all other agents, it lives in a container and migrates within the platform. The main-container can be replicated via replication service [5,27–30] (Figure 2).

3.2.2. Agent subsystem architecture.

The architecture is described in Figure 2. It relies upon an agent; its container is split into a FrontEnd on the handheld device and a BackEnd running on a J2EE host. We put the Geo-Data in the BackEnd of container. Wireless devices gain the services from the agent, which run on the FrontEnd of a split container. Filtering and personalization take place on the server or on the browser, to analyze what is the best.

Agent-based system is intrinsically peer to peer; each agent is a peer that potentially needs to initiate a communication with any other agent as well as providing capabilities to the rest of the agents. Agent subsystem here is served as middleware between end users and the services. It enables easier and more effective application developments by providing generic service, which is useful not only for a single application but also for a variety of applications.

3.2.3. Agents communication.

We use the language defined by FIPA: Agent Communication Language (ACL) as agent communication language.

In the application based on Web, agent communication can be self-identified and web page-like data structures. Agents communicate with other agents either directly or by inserting the keyword and parameters into the text of a transferring page. Each page also incorporates with other web-based markup languages, including the Geographical Markup Language (GML), which is the description of Geography maps and the Resource Description Framework (RDF) that needed in ontology.

JADE-LEAP agent is a standard FIPA, ACL messages can be exchanged between agents. There are a set of attributes as defined by the FIPA specifications. According to FIPA specifications, a reply message with a set of well-formed rules can be formed. By transmitting a sequence of bytes over content of ACL messages, some applications can be realized. Since JADE provides several methods to set/get a sequence of bytes in/from the content of the ACL message, GIS data update can be realized.

FIPA specifies a set of standard interaction protocols, which can be used as standard templates to build agent conversations in JADE, like FIPA-Request, FIPA-query, FIPA-Request-When, FIPA-recruiting, and FIPA-brokering.

During complex conversation, which is a sequence of messages exchanged by two or more agents with well defined causal and temporal relations, agents can communicate to each other by interaction protocol, including sending messages, receiving messages, performative, blocking, waiting, and so on.

4. GIS DATA MANAGEMENT

4.1. MAP data base manager

Spatial information database is an infrastructure of the location-based context-aware service. The database

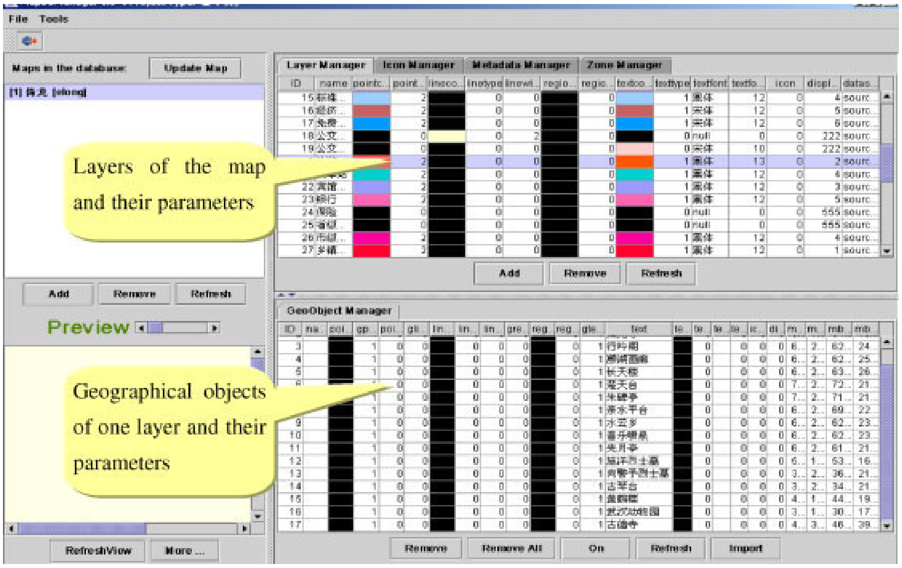

Figure 3. An interface of MDM.

manages the geometric information of the ubiquitous computing environments, such as location of users and surrounding mobile devices. We have developed the kit based on representation of the GIS data based on GML. GML is the standard protocol for encoding spatial data based on XML. The kit can convert various formats GIS data of ArcGIS, Mapinfo into our GML information, and our kit is named as Map Database Manager (MDM). In our system, there are two advantages to use GML geographical data instead of ArcGIS or Mapinfo data. One advantage is that no commercial software will be needed to plug in handheld devices, which will be required if we use ArcGIS or Mapinfo data. Another advantage is GML geographical data can be dealt with easily in web server and can be applied in other system since it is based on open protocol of XML.

The interface of MDM is shown as Figure 3. In MDM, when we add the map which has the general formats of ArcGIS or Mapinfo, the map will be converted into GML data, just as displayed on the right of the window in Figure 3. In the top right, there are some layers of map. When a layer is selected, geographical object of the layer and its parameter values will be displayed in the lower right of the window. By MDM, the map layers and road segment datasets we needed can be selected and applied in our system.

We characterize the MDM with the function as follows:

(1) Provide an open, vendor-neutral framework for the definition of geospatial application schemas and objects;
(2) Allow profiles support proper subsets of GML framework descriptive capabilities;
(3) Support the description of geospatial application schemas for specialized domains and information communities;
(4) Enable creating and maintaining geographic application schemas and datasets;
(5) Support the stoppage and transport of application schemas and datasets; and
(6) Increase the ability of organization and share geographic application schemas or information they described.

An example of the code in MDM is briefly presented in Figure 4. Based on a simple model of the mark in map, it describes the name and coordinates of a ground object "General Park" and some characters of the layer that this ground object is located in.

4.2. Prototype of the system on Motorola mobile phone

The system with the basic GIS/GPS function has been applied in Nokia mobile phone firstly. Then multi-agents and optimal path analysis module has been added. In order to lay out the prototype results clearly, the screenshots of emulator instead of real mobile devices photos are used. Figure 5 is the screenshots of the system prototype in Motorola Mobile Phone, including four parts. Part a is the first step that the system is logged in with user's name and pin #. Then the map can be browsed in detail, like part b. Besides of browsing function, users can search some labels in map by fuzzy match according to the inputted querying label data, displayed as part c. In the prototype, some nodes (labels) on the map are selected and the optimal path based on both distance and travel time can be queried and displayed, demonstrated as part d.

To achieve high performance in GIS/GPS application to handheld J2ME-MIDP devices, peer to peer multi-agents

```
<?xml version="1.0" encoding="GB2312" ?>
<! - - File:  Map.XML - - >
<gml:Location>
 <gml:Layer>
     <gml:ID> 110190000 </gml:ID><gml:Name> BusStation </gml:Name><gml:PointColor> -16777216 </gml:
     PointColor><gml:PointSize>0</gml:PointSize><gml:LineColor>-16777216</gml:LineColor><gml:LineType>0</gml:LineType><gml:LineWidth>
     0</gml:LineWidth><gml:RegionColor>-16777216</gml:RegionColor><gml:RegionType>0</gml:RegionType><gml:TextColor>-13108</gml:
     TextColor><gml:TextType>0</gml:TextType><gml:TextFont>Song Ti </gml:TextFont><gml:TextSize>0</gml:TextSize>
     <gml: TextSize>0</gml:TextSize><gml:Icon>0</gml:Icon><gml:Level>222</gml: Level>
    <gml: GeoObj >
           <gml:ID>110190001</gml:ID><gml:Name></gml:Name><gml:MBR_X_MIN 318.2145</gml:
           MBR_X_MIN><gml:MBR_Y_MIN>487.07626</gml:MBR_Y_MIN><gml:MBR_X_MAX>318.2145</gml:MBR_X_MAX>
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           <gml:GeoPoint> <gml:Metapoint><gml:X>318.2145</gml:X><gml:Y>487.07625</gml:Y> </gml:Metapoint>
           </gml:GeoPoint>
       <gml:GeoText>
                  <gml:name> General Park </gml:name>
                  <gml:Metapoint><gml:X>318.2145</gml:X><gml:Y>487.07625</gml:Y></gml:Metapoint>
         </gml: GeoText >
     </gml: GeoObj >
 </gml:Layer>
</gml:Location>
```

Figure 4. The coding example: a section of the map mark in GML.

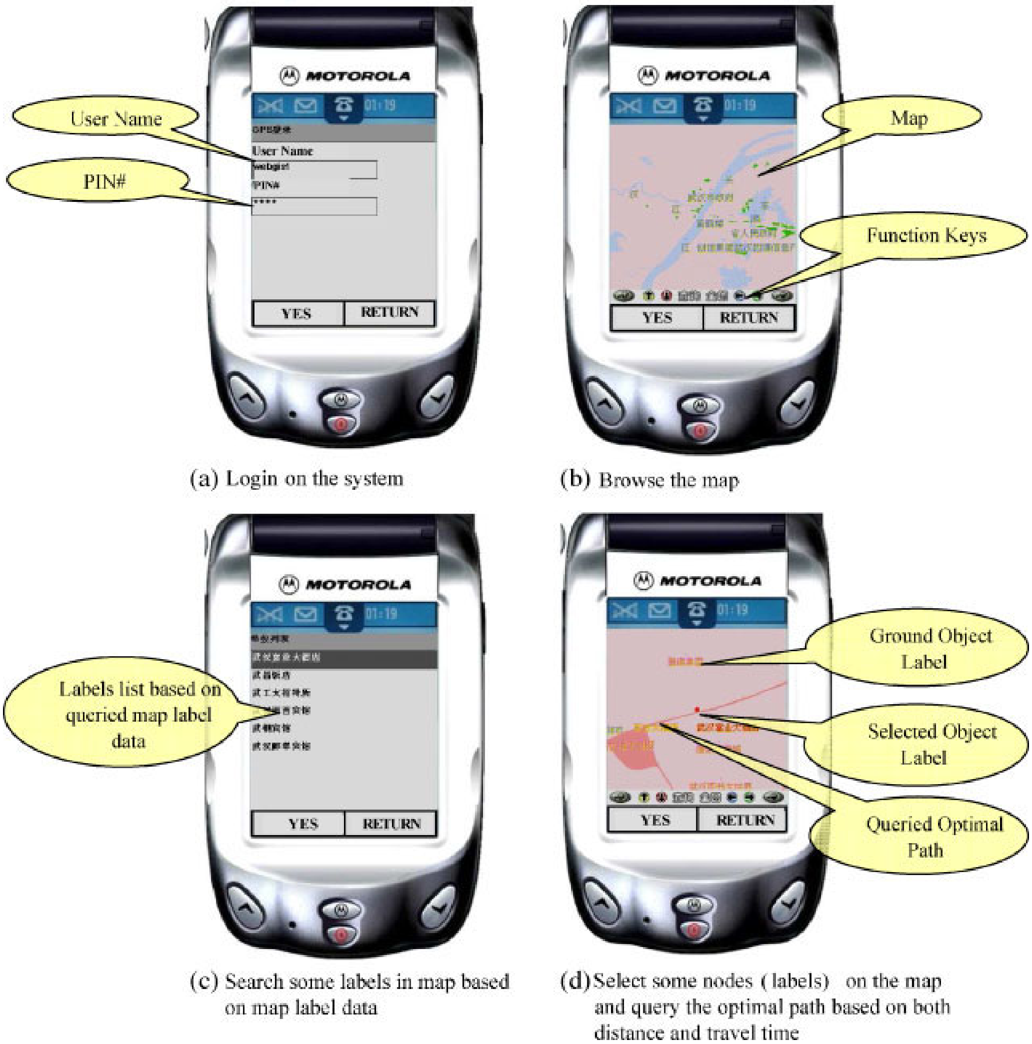

Figure 5. A prototype of system on mobile phone.

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based cooperative design is used, which can not only distinguish adaptively to handheld devices and to user's profiles but also can be applied in distributed GIS. The architecture offers system flexibility and extensibility in the displaying, inquiring, and updating of geographical data. Further work can be done to adapt and aware bandwidth, ability of devices, status of traffic aforehand and fit the different characters, and capability of mobile devices by using multi-agents.

RDF, XML, and GML are utilized to represent the geo-agents ontology. Map Manager in our system can convert various formats of ArcGIS and Mapinfo GIS data into our GML information, which is fit for distributed GIS implementation.

5. OPTIMAL PATH SEARCH IN TIME TRANSPORT NETWORK

5.1. The time transportation network graph model

It is the simplest way for Optimal Path Search to directly comparing path length and select the shortest path. But this method does not take traffic congestion into account. Sometimes, the shortest path is excessive with traffic jam, and takes more time [31]. Therefore, traffic volume, road conditions, and other facts must be considered in the best routing algorithm. So we should re-define the weight of each traffic path with the traffic states, in which optimal path can be determined according to the last weight value [32].

In network model, nodes are objects to be linked mutually. A digitization spatial network is generated as a modeling graph from the input spatial objects. The modeling graph contains three categories of graphs: the network junctions, the start/end points of a road segment, and other auxiliary points (such as speed limit change points). In order to reflect some factors in network model, such as traffic volume, the road conditions, and other real time traffic factors, the path between two nodes A and B is identified by the travel time to reflect the above factors. The value of the path between nodes A and B will act as a weight, which will be added to original spatial model and form the new time transportation network graph model [33].

5.2. Speed-flow relationship model parameters

To analyze the traffic condition in all levels roads, traffic flows, speed, and road states are considered, which are accessed as the basic data of the distance in time transportation network. Currently, the information access of freeway based on the video monitor, microcontroller and traffic monitoring systems, and other means is carried out in full swing [34]. There are a lot of mature road infrastructure and monitor technologies in the world now [35]. Wang *et al.* [36] collected 30 thousand sample data from 279 road sections, 20 intersections, and 2l toll stations, over a period of 4 years, cover a large area in China including many province. After analyzing these data, the speed-flow relationship field data models and the standardized models are established. Generic function expression is described as formula (1), where the practical traffic conditions are modeled based on defined model parameters.

Table I. The highways speed-flow generic model table.

Highway types	U_S (km · h^{-1}) design speed	C (pcu · h^{-1}) traffic capaity	α_1	α_2	α_3
Highway	120	2200	0.93	1.88	4.85
	100	2200	0.95	1.88	4.86
	80	2000	1.00	1.88	4.90
	60	1800	1.20	1.88	4.88
A level road	100	2100	0.93	1.88	4.93
	80	1950	0.98	1.88	4.88
	60	1650	1.10	1.88	4.85
B level road	80	1400	0.95	1.88	6.97
	40	900	1.40	1.88	6.97
C level road	40	600	1.00	1.88	7.00
	20	400	1.50	1.88	7.00

$$\left.\begin{aligned} U &= \frac{\alpha_1 U_s}{1+(V/C)^{\beta}} \\ \beta &= \alpha_2 + \alpha_3 \left(\frac{V}{C}\right)^3 \end{aligned}\right\} \tag{1}$$

As shown in Table I, parameters α_2, α_3 have very small variation. Therefore, for the sake of simplicity in calcu1ation, it is reasonable to take $\alpha_2 = 1.88$. For a highway and a class road, set $\alpha_3 = 4.90$. While for a general road (include B class road and C class road), set $\alpha_3 = 7.00$.

According to the above model, a highway traffic control speed-flow model (SFM) can be created. In the SFM, based on the real time monitoring of traffic flow on each road in given areas, and the given parameters, the average travel time and average speed in each road section can be predicted, it is very useful to distribute the transportation network.

5.3. Incremental Euclidean restriction (IER) algorithm optimize

5.3.1. IER algorithm.

Usually, the shortest path between two points or for a moving object in traffic is always moved in the defined networks (such as roads, railways). Therefore, for the travel between two objects, the calculation of the distance among the space network is much more appropriate than the calculation of a purely Euclidean distance. In Reference [37], the Incremental Euclidean Restriction (IER) algorithm and Incremental Network Expansion (INE) algorithm are proposed to resolve the nearest neighborhood query problems in space network. In this paper, based on the SFM, we modify and improve the IER algorithm to solve the optimized path query problem in time transportation networks.

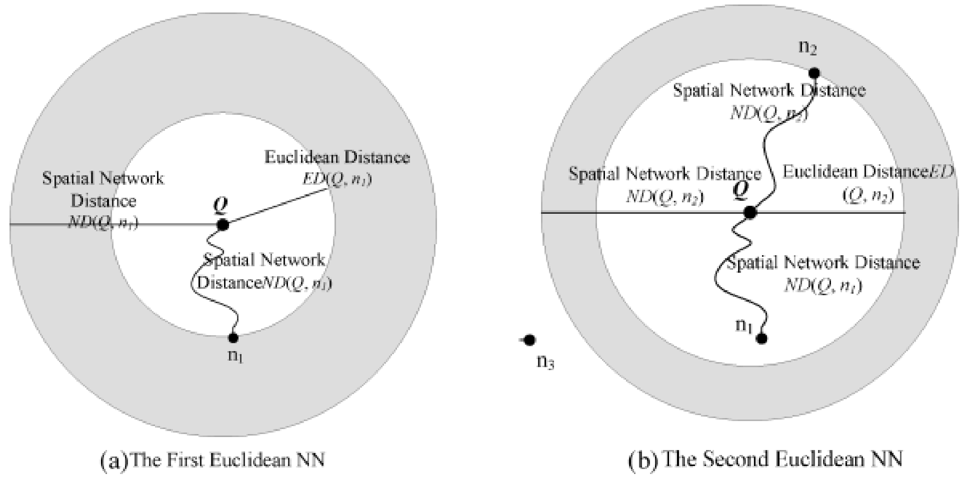

Figure 6. IER algorithm.

In IER algorithm, the multi-step K-Nearest Neighbor (KNN) method [37] is used to get high dimensional data similarity. With common incremental KNN algorithm, the nearest neighbor nodes of node Q are searched as following. Firstly, IER retrieves the nearest neighbor of Q, and marks it as n_1. Based on Euclidean distance, we calculate the Euclidean distance between them, which is marked as ED (Q, n_1). Secondly, we calculate the distance of Q and n_1 in space network, which is marketed as ND (Q, n_1). Subsequently, the IER algorithm can use Q as the center to draw two concentric circles with radii ED (Q, n_1) and ND (Q, n_1), respectively. Due to the Euclidean lower bound property (i.e., for any two nodes i and j, their Euclidean distance ED($n_{i,\ j}$) always provides a lower bound on their network distance ND($n_{i,\ j}$)). Objects closer to Q than n_1 in the space network must be within the circle, which is made by ND (Q, n_1) as its radius. Therefore, the search space becomes the ring area between the two circles as shown in Figure 1. In the next iteration, the second closest object n_2 is retrieved (by Euclidean distance). Since in the given example ND (Q, n_2) < ND (Q, n_1), n_2 becomes the current candidate for spatial network nearest neighbor and the reach upper bound becomes ND (Q, n_2). This procedure is repeated until the next Euclidean nearest neighbor is located beyond the reach region (as n_3 in Figure 6).

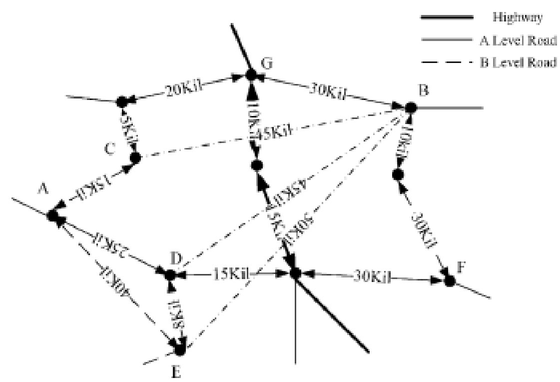

Figure 7. Space network.

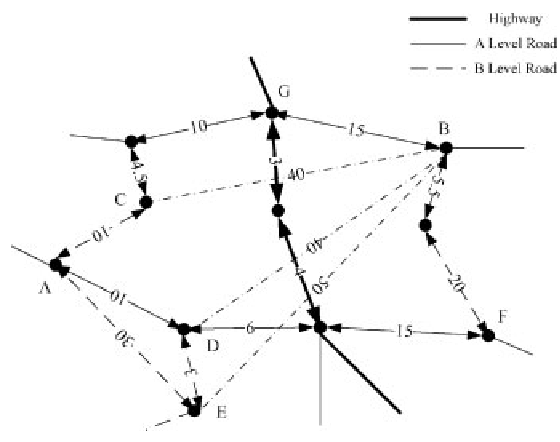

Figure 8. Time road transportation network.

5.3.2. Algorithm Exp-IER expansion of the IER.

In this paper, we use time transportation network to replace the space network in IER algorithm and propose Exp-IER algorithm. The time transportation network enables the integration of real time traffic information into a spatial representation [38]. The spatial distance between two points of IER is replaced by the travel time, which can measure road and traffic conditions. Figures 7 and 8 illustrate the use of travel time in the path of the road map.

The travel time of node n_i–n_j along one road can be marked as the cost of the path between two nodes, and it is also shown as the weight of the path. From the speed-flow generic model, and based on formula (1), we can get (2).

$$\cos t_{n_i n_j} = \frac{\mathrm{Dist}_N(n_i, n_j)}{U_{n_i n_j}} = \frac{\mathrm{Dist}_N(n_i, n_j)\left(1+(V_{n_i n_j}/C)^{\beta}\right)}{\alpha_1 U_s} \qquad (2)$$
$$\beta = \alpha_2 + \alpha_3(V_{n_i n_j}/C)^3$$

The dynamic weights of each path can be gotten from the speed-flow generic model, but in the calculation of KNN process, if all the distance comparison is concerned with the dynamic traffic flow, it will reduce the efficiency of the optimized path querying greatly. Therefore, it is not feasible to calculate the travel time of each path by the real-time inquiring of flow status V. In the searching process of the shortest path node, it is available to use the ratio parameter of dynamic changed flow Vn_in_j to road capacity C as a weight, which is used to evaluate the traffic status. According to the weights V/C, the traffic can be divided into the following four categories:

Category 1–Expedite: In this path, the traffic flow is small, speed limits are reached, $0 < V/C < 0.8$.

Category 2–Normal: Traffic flow in this road is under normal conditions, speed is little lower than designed speed, $0.8 \leq V/C < 0.95$.

Category 3–Slow: A road segment traffic will exceed its capacity, but still can contain travel forward, the vehicle speed is below the speed designed, $0.95 \leq V/C < 1.2$.

Category 4–Congestion: The real traffic speed of a road segment is much lower than the speed limit, and vehicles need to waiting in line, $V/C > 1.2$.

Category 5–Detour: A road segment is closed and mobile host has to take a circuitous route, the actual flow of V is zero.

The weights V/C can be calculated in the system separately, so that users can choose the best path when targets are set to filter unnecessary path computation. Meanwhile, by accessing the speed-flow model SFM, traffic flow, vehicle speed, and some parameters relatively with them in a given road segment, and a given time can be gained immediately. They are associated with the following algorithm. If we set out from one point in a given time, the destination (that meets the requirements on maps) and the optimal path to the destination can be gained.

Figure 9. Weight of road.

Figure 9 is a simulation of the value of the weight information dialog interface, which describes the real-time flow of the road. After the filtering of other unused map layer, a clear road linked map is used, and the traffic load weights V/C of the specified road are displayed when users query it.

5.3.3. Time transport network's optimal path search.

For the optimal path searching, we divide the process into two parts. One is searching the nearest neighbor in the time traffic network (TTN), which is designed as Exp-IER algorithm. Another part is to search the optimal path between the nearest neighbor nodes that found by Exp-IER algorithm, which is described by GNN algorithm.

In the Exp_IER algorithm, the spatial distance between two points of IER is replaced by the travel time, which can measure road and traffic conditions. At the same time, the traffic load of each road segment should be taken into consideration. If a road segment traffic type is Category 4 or Category 5 that mentioned in Section 5.3.2, then all corresponding destination nodes in this road segment are removed from the search area. The Exp_IER algorithm is shown as following.

Algorithm 1 The Nearest Neighbor searching in TTN.

```
Algorithm  Exp_IER(Q,k)

 for all k nearest neighbors in road segment (Q, n)
 of TTN
    from i = 1 to k
    if 0<V / C(Q, n_i) < 1.2
        {n_1, ..., n_k} = Euclidean_NN(Q, k)
        else  n_{k+1} = next_Euclidean_NN(Q, k)
            delete n_i from {n_1, ··· , n_k}
            insert n_{k+1} in {n_1, ··· , n_k}
    for each point n_i
    Dist_N(Q, n_i) = compute_ND(Q, n_i)
    sort {n_1, ··· , n_k} in ascending order of Dist_N(Q, n_i)
    Dist_E_max=Dist_N(Q, n_k)
    repeat
        if 0 < V / C(Q, n) < 2
            (n, Dist_E(Q, n)) = next_Euclidean_NN(Q)
                if (Dist_N(Q, n)) < Dist_N(Q, n_k)
                    insert n in {n_1, ..., n_k}
                    Dist_E_max = Dist_N(Q, n_k)
    until Dist_E(Q, n) > Dist_E_max
End Exp _ IER
```

Assuming one user is in the position A, we use the improved Exp_IER method to implement A road space NN inquiries, and gain a nearest neighbor in B position. Next, we should ensure the best path to reach B from A.

In this step, the path is also considered in TTN. Based on the SFM, the weights of the road and traffic conditions are used to calculate the traffic time cost of each path from A to B, and to find the shortest time one, which is the optimized path we want to get.

Algorithm of Greedy Nearest Neighbor Graph Path: GNN (q, k) is shown as following.

Algorithm 2 Greedy Nearest Neighbor Graph Path searching in TTN.

Algorithm $GNN(q, k)$

$\{n_1, \ldots, n_k\}$ = Exp_IER(q, k)

$result = \{(q, n_1), \ldots, (q, n_k)\}$

for each surrounding road segment (q, n_i) in the TTN do

$Dist_N(q, n_i) = compute\_ND(q, n_i)$

$\{\alpha_1, \alpha_2, \alpha_3, V_{qn_i}, C, U_S\}$ = Speed-Flow(q, n_i)

$\beta = \alpha_2 + \alpha_3 (V_{qn_i} / C)^3$

$$\cos t_{qn_i} = \frac{Dist_N(q, n_i)\left(1 + (V_{qn_i} / C)^{\beta}\right)}{\alpha_1 U_S}$$

$cost_{\min} = \min\{cost_{qn_1}, \ldots, cost_{qn_k}\}$

select the path from q to one point which has the minimum traffic time cost $cost_{\min}$

END $GNN(q, k)$

6. ALGORITHM PERFORMANCE ANALYSIS

Using three types of reference data sets: highway, A level road and B level road, we simulate and test the optimized path Search algorithms of Exp-IER and GNN in time transportation network. In the simulation, it is necessary to consider not only the different road level such as highway, A level road and B level road on maps, but also the path selection among same type roads. Test parameters include the travel distance, travel time, traffic load V/C, comparison of actual time cost to the previous time cost (in space distance network, travel time is not considered), and the average driving time saving rate.

Simulation is carried on the computer, which has Pentium IV, 2.3 GHz processor and Windows 2003. The road segment is $|n| = 1000$, including urban and rural highways, city A level road, urban and rural B level roads.

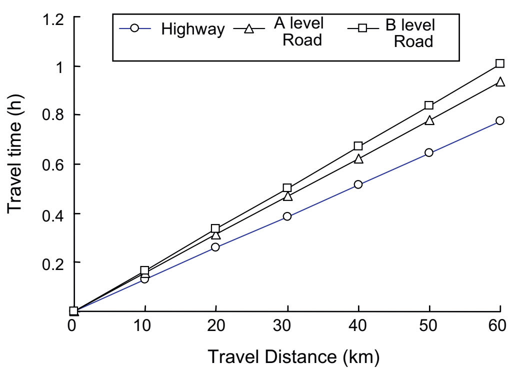

Figure 10. Comparison of the travel time in different types of roads.

Table II. Road designed speed limit, capacity, and other parameters.

Highway types	U_S (km·h^{-1}) design speed	C (pcu·h^{-1}) traffic capacity	α_1	α_2	α_3	V/C
Highway	100	2200	0.95	1.88	4.86	0.6
A level road	80	1950	0.98	1.88	4.88	0.6
B level road	60	1150	1.17	1.88	6.97	0.6

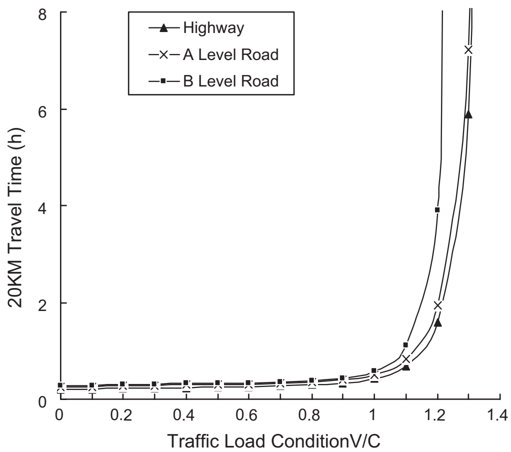

Figure 11. 40 km distance travel time.

6.1. The impact of road type on the travel time

In Figure 10, vehicles set out from a point and travel in different types of road. Corresponding to the increase of the travel distance, more of the average time is required. In the simulation, designed vehicles speed limits, capacity, and other parameters of each type of road are set on Table II.

Based on the test and graph, if the traffic is in the same situation and moves the same distance, it is clear that the different types of vehicles on the road will need different time. Therefore, highway will take shortest time, and B level road will take longest time.

In the algorithm, in the same distance traffic load conditions, the path with shortest time ($\text{cost}_{\min}$) on the road will be selected. According to the results in graph, it can be concluded that it is very necessary to replace the space network model by the time transportation network model to measure the optimal path querying.

6.2. The impact on the travel time of traffic load *V/C*

Traffic flow condition can be predicted by the traffic load weight V/C, so the average vehicle speed and the travel time at a certain distance can be predicted. Figure 11 and Figure 12 describe the average travel time that vehicles need in 40 km distance in different road types and traffic load.

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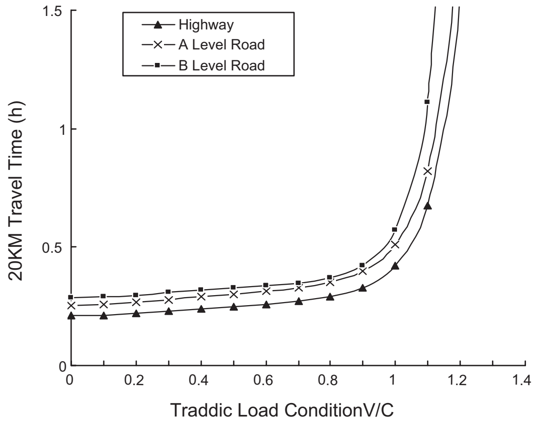

Figure 12. 20 km distance travel time (enlarge).

From the graphs, we can get that when weight of *V/C* is from 0 to 0.8, vehicles can maintain normal travel and have no block. Going with the increase in the weight value, i.e., the travel flow value is increasing, travel time will be increased correspondingly. When the traffic load is from 0.8 to 0.95, vehicles can still maintain a certain speed to travel, while the cost time for vehicles is more than 1/3 normal traffic load. When weight of *V/C* is close to 1.2, the travel time is increased rapidly, and the traffic congestion condition seems to be impossible to complete the travel in such a road segment practically.

The travel status in graph also reflects the four categories of road travel status which are classed based on traffic load weight *V/C*, i.e. Normal, Slow, Congestion, and Detour. Meanwhile, it can also be concluded from graphs that along with the changes of traffic load in highway, A level road and B level road, the travel time are changed *pro rata*. In the same traffic load condition, highway costs the shortest travel time.

6.3. The average time saving rate of optimal path search in time transportation network

In this paper, we use the time transportation network to replace the original space network and expand the original shortest path query method in the space network. Based on the target node and buffer inquiries information, our model can choose a path adaptively from setting out node to target node, which costs the shortest time. The chosen path is the optimized path considering traffic conditions. In the experiment, three kinds of road are considered when we calculate optimal path, i.e., highway, A level road and B level road. We use the travel time saving rate to measure the performance difference between our algorithm and the shortest path querying method in space network. We define Time Savings Rate to weigh the performance, in the different traffic load condition. It is the ratio of saving travel time of the new method IER-EXP in this paper than the travel time in original method IER in space network,

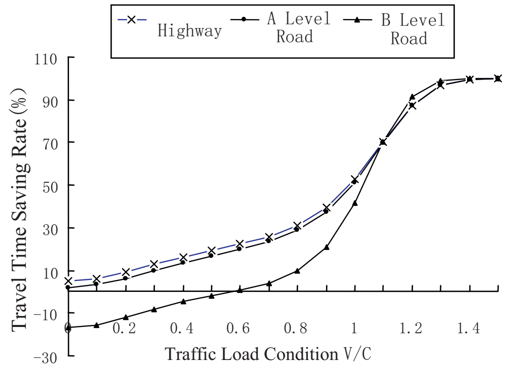

Figure 13. Average travel time saving rate in each road type traffic load.

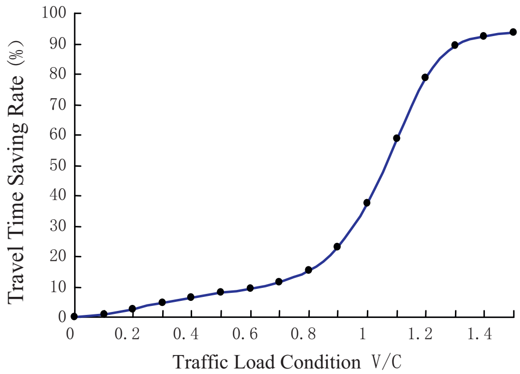

Figure 14. Average travel time saving rate in different traffic load.

which is quantized as $(\text{cost}_{\text{SN}} - \text{cost}_{\text{TTN}})/\text{cost}_{\text{SN}}$. It reflects how the travel time is saved in optimized path query time transportation network compared to space network in the same known condition and user requirement.

Figure 13 is the average savings rate, which only considers road type data sets. Figure 14 is the average savings rate of IER-EXP method to original IER method with the increase of traffic load condition, which considers integrated data sets with all kinds of road types. The choice of the optimal path is not limited by road type restrictions. From the graph, it can be concluded that along with the increase of traffic load, the consideration of road traffic conditions in our algorithm get a larger saving rate.

6.4. The average travel time of IER and Exp_IER Algorithm

Average travel times based on IER and Exp_IER algorithm are tested in the same road segment respectively (Figure 15). The road segment is $|n| = 1000$, including urban and rural highways, city A level road, urban and rural B level roads. In IER algorithm, the space road network is used, which only considers the spatial distance between two points. In Exp_IER algorithm, the spatial distance is replaced by the travel time, which can measure road and traffic conditions.

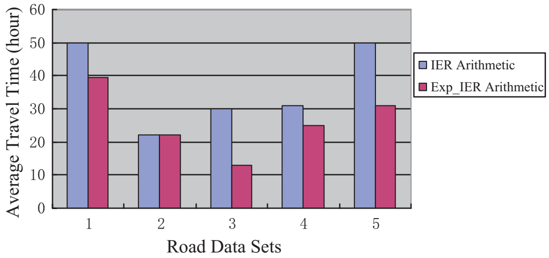

Figure 15. IER algorithm *versus* Exp_IER algorithm about the average travel time.

Since the IER algorithm considers the shortest distance only, in the test 1, 3, 4, and 5, the road segment includes three kinds of road with different traffic load and travel time, the path that IER selects will cost more travel time than Exp_IER algorithm's. In the test 2, both IER and Exp_IER algorithm select the same path because the shortest distance is equal to the optimal distance exactly. Therefore, the travel times they spend are equal to each other.

7. CONCLUSION AND FUTURE WORK

As mobile computing is more and more widespread, mobility support for Internet devices becomes very important. Mobility management for wireless network is a promising technology that provides the seamless mobile communications. In this paper, we focus on the mobile GIS management system based on multi-agents. To achieve high performance in GIS/GPS application in handheld J2ME-MIDP devices, peer to peer multi-agents based cooperative technology is used, which can not only distinguish adaptively to the specific device and to user's profile, but also can be applied to distributed GIS. The architecture offers system flexibility and extensibility in the displaying, inquiring, and updating of geographical data. A lot of work can be done to adapt and aware bandwidth, ability of devices, status of traffic aforehand and fit the different character, and capability of mobile devices by use of multi-agent.

RDF, XML, and GML are utilized to represent the geo-agents ontology. Map Manager in our system can convert various formats GIS data of ArcGIS, Mapinfo into our GML document, which is fit for distributed GIS implementation.

Furthermore, the optimal path query problem, a very important GIS service issue is dealt primarily in this paper. Traditional GIS buffer inquiries only focus on the length of the road path in a map. In this paper, an expanded method is proposed to support the distribution of mobile GIS services. According to the user's requirement and the known buffer's area radius in a map, we defined the factors to calculate the optimal path from one node to the target node in a map. The factors include not only the length of the road but also traffic flow, road cost, and other factors. The integrated cost is used to re-define the road path weights, and the optimal path among the roads is selected based on the minimum weight. The actual experimental results demonstrate that in the search process, based on the quantified traffic flow and road condition, from node to other target nodes, an optimal path on map can be obtained, which satisfies the condition mostly. The results can greatly assist the inquiry of the optimal path in GIS services.

Future work will focus on implementing more rich services on our system and applying mobile agent mechanism in our system.

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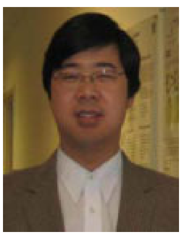

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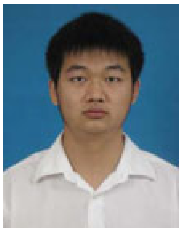

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