Efficient evaluation of shortest travel-time path queries through spatial mashups

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Abstract In the real world, the route/path with the shortest travel time in a road network is more meaningful than that with the shortest network distance for location-based services (LBS). However, not every LBS provider has adequate resources to compute/estimate travel time for routes by themselves. A cost-effective way for LBS providers to estimate travel time for routes is to issue external route requests to Web mapping services (e.g., Google Maps, Bing Maps, and MapQuest Maps). Due to the high cost of processing such external route requests and the usage limits of Web mapping services, we take the advantage of

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direction sharing, parallel requesting and waypoints supported by Web mapping services to reduce the number of external route requests and the query response time for shortest travel-time route queries in this paper. We first give the definition of sharing ability to reflect the possibility of sharing the direction information of a route with others, and find out the queries that their query routes are independent with each other for parallel processing. Then, we model the problem of selecting the optimal waypoints for an external route request as finding the longest simple path in a weighted complete digraph. As it is a MAX SNP-hard problem, we propose a greedy algorithm with performance guarantee to find the best set of waypoints in an external route request. We evaluate the performance of our approach using a real Web mapping service, a real road network, real and synthetic data sets. Experimental results show the efficiency, scalability, and applicability of our approach.

Keywords Path queries · Travel time · Spatial mashups · Direction sharing · Parallel requesting · Waypoints · Web mapping services

1 Introduction

A spatial (or GIS/mapping) mashup [16, 35–38] provides a cost-effective way for a Web or mobile application that combines data, representation, and/or functionality from at least one Web mapping service and other local/external services to create a new application. It becomes more and more popular along with the development of Web mapping services and the ubiquity of Internet access and GPS-enabled mobile devices. Typical Web mapping services are Google Maps [8], MapQuest Maps [22] and Microsoft Bing Maps [23]. Based on the latest statistics of Programmable Web [25], the spatial mashup is the most popular one among all types of mashups including search mashups, social mashups, etc.

In the real world, the route with the shortest travel time (e.g., driving, walking and cycling time) in a road network is more meaningful than the route with the shortest network distance for location-based services (LBS) (see Fig. 1). Since travel time is highly dynamic due to many realistic factors, e.g., heterogeneous traffic conditions and traffic accidents, it is difficult for an LBS provider to perform travel route estimation/computation because of huge deployment cost. However, it is not a big problem for Web mapping service providers, as they have adequate resources to collect data from historical traffic statistics and/or continuously monitor the real-time traffic in road networks; besides, most of existing Web mapping services provide user-friendly APIs for applications to access travel route information, e.g., the Google Maps Directions API [27] and the MapQuest Directions Web Service [21].

Therefore, a typical and popular application scenario using spatial mashups is that an LBS provider subscribes the travel route information based on live traffic conditions from Web mapping services through their APIs to answer location-based queries for its own users [16, 35–38]. For example, Yelp.com [34], which is a leading Internet consumer rating and review Web site, outsources its mapping services to Google Maps [8], among which retrieving and then displaying the travel route information from a user's current/specified location to a point-of-interest (POI) makes the Web site more intuitive and attractive.

However, retrieving the travel route information through spatial mashups suffers from the following two critical limitations [36, 37]: (1) It is costly to access travel route information from a Web mapping service, e.g., retrieving travel time from the Microsoft MapPoint Web service to a database engine takes 502 ms while the time needed to read a cold and hot 8 KB buffer page from disk is 27 ms and 0.0047 ms, respectively [14]. (2) There is a charge on the number of requests issued to a Web mapping service, e.g., the Google Maps Directions

Fig. 1 The two different routes from Times Square to New York Stock Exchange by Google Maps (the blue/right one is with the shortest travel time, which is recommended by Google, and the gray/left one is with the shortest network distance)

API [27] allows only 2,500 requests per day for evaluation users and 100,000 requests per day for business license users [9]. An LBS provider needs to pay for higher usage limits. Therefore, when an LBS provider endures high workload, e.g., a large number of concurrent user queries, it needs to issue a large number of external route requests to Web mapping services, which not only result in high business operation cost, but also induce long response time to querying users.

In this paper, we aim to explore direction (or route/path) sharing optimization and appropriate waypoints in *external route requests* with parallel requesting to Web mapping services to reduce the number of external route requests and the response time to querying users for LBS providers.

Given user u_i 's *shortest travel-time path query* $q_i = (o_i, d_i)$, the basic idea of the direction sharing optimization is that the route information from query origin o_i to query destination d_i (i.e., $R(o_i \rightarrow d_i)$) can be shared with another user u_j 's query $q_j = (o_j, d_j)$ if both of its origin o_j and destination d_j are located in $R(o_i \rightarrow d_i)$. To reflect the opportunity of sharing the direction information of an external route request, we also formally define the *sharing ability* of a route. Besides, the queries whose querying routes are *independent*, i.e., they are not the sub-route of each other, are detected out for parallel processing to reduce the user query response time.

As most of existing Web mapping services that support adding waypoints into a route request, e.g., Google Maps allows up to eight intermediate waypoints in a route request for evaluation users and 23 intermediate waypoints for premier users [9], we attempt to select optimal waypoints in a route request to further reduce the number of external route requests and the query response time to users. We first model the problem of selecting optimal waypoints in a route request, i.e., the route through those waypoints can be shared

by the largest number of queries, as the problem of finding the longest simple path in a weighted complete digraph. As it is a MAX SNP-hard problem, i.e., there is no polynomial-time algorithm that can even find a constant factor approximation for the problem unless $P = NP$ [13], we propose a greedy algorithm with performance guarantee to find the best set of waypoints in an external route request. The algorithm guarantees that at least $\lfloor \frac{m}{2} \rfloor$ queries in the query set Q can share the direction information of a returned route from Web mapping services, and tries to maximize the direction sharing optimization of the route at the same time, where m is the number of waypoints in a route request.

In general, the main contributions of our work in this paper can be summarized as follows:

- We formally define the sharing ability of a route to reflect its direction sharing power, and design an algorithm to compute it.
- We find out the queries whose querying routes are independent for parallel processing to reduce the query response time to users without bringing in additional external route requests.
- We formulate the problem of selecting optimal waypoints in a route request, and propose a greedy algorithm with performance guarantee to solve it.
- We design an algorithm with all the optimizations (i.e., direction sharing, parallel requesting, and waypoint utilization) proposed in the paper.
- We conduct extensive experiments to evaluate the performance of the proposed optimizations using real a Web mapping service, a real road network, real and synthetic data sets.

The remainder of this paper is organized as follows. Section 2 highlights related work. Section 3 describes the system model. Section 4 presents the direction sharing optimization. Section 5 describes the route waypoint optimization. Section 6 gives an algorithm with all the optimizations proposed in the paper. Experimental results are analyzed in Section 7. Finally, Section 8 concludes this paper.

2 Related work

Queries have been widely used in our daily life [11, 15, 17–20, 32, 41], among which the shortest path query is one of the most important types. Existing shortest path query processing algorithms in road networks can be categorized into two main models:

(1) **Time-independent road networks.** In this model, shortest path query processing algorithms assume that the cost or weight of a road segment (e.g., distance or travel time) is constant (e.g., [26, 33, 39]). These algorithms mainly rely on pre-computed distance or travel time information of road segments in road networks. However, the actual travel time of a road segment may vary significantly during different time of a day due to the dynamic traffic on road segments [5].

(2) **Time-dependent road networks.** The shortest path query processing algorithms designed for this model have the ability to support the dynamic weight of a road segment and topology of a road network, which can change with time. This model is more realistic but more challenging. George et al. [7] proposed a time-aggregated graph, which uses time series to represent time-varying attributes. The time-aggregated graph can be used to compute the shortest path at a given start time or to find the best start time for a path that leads to the shortest travel time. In time-dependent road networks where the weight of each road segment is a function of time, problems of the time-dependent shortest-path [5, 6] also

have been extensively studied. The solutions for those problems may capture the effects of periodic events (e.g., rush hours, and weekdays). However, they still cannot reflect live traffic information, which can be affected by sudden events, e.g., congestions, accidents, and road maintenance. Hence, another interesting approach for shortest path query processing is to let the server (e.g., NAVTEQ [24], and INRIX [12]) collect live traffic information and then broadcast them over radio or wireless network to clients, who listen to the live traffic index and read the relevant portion of the index for deriving the shortest path by themselves [31, 40].

This paper focuses on the shortest travel-time route (or path) queries in time-dependent road networks. Our work distinguishes itself from previous work in that it does not model the underlying road network based on different criteria [5–7], or broadcast live traffic information to clients [31, 40]. Instead, it employs external Web mapping services, e.g., Google Maps, to provide the real-time route information in a road network through their user-friendly APIs.

There are some works about query processing with expensive attributes that are accessed from external Web services (e.g., [2, 3, 14, 16, 35–38]). To minimize the number of external requests, [2, 3, 14] mainly focus on using either some *cheap* attributes that can be retrieved from local data sources [2, 14] or sampling methods [3] to prune a whole set of objects into a smaller set of candidate objects; then, they only issue necessary external requests for retrieving candidate objects.

In [36–38], the authors proposed k -NN query processing algorithms that utilize grouping, direction sharing, shared query execution, pruning techniques, and parallel requesting to reduce the number of external requests to Web mapping services and provide highly accurate query answers. In [16], route logs are employed to derive tight lower/upper bounding travel times to reduce the number of external Web mapping requests for answering range and k -NN queries. However, none of these existing techniques focuses on how to utilize waypoints in an external route request to reduce the number of such expensive requests.

The closest work to our paper is [35], where the authors assume that the route with a longer network distance has a higher possibility of sharing its route information with others (i.e., sharing ability), and then they select waypoints in a route request only based on the network distance. In fact, this assumption is not always correct as user queries are not completely uniformly distributed in the underlying road network. Therefore, we select waypoints by sharing ability in this paper, which is computed based on the historical route information and the road network model; besides, the queries that their querying routes are independent with each other are found out for parallel processing, to reduce the query response time to users without bringing in additional external route requests.

3 System model

In this section, we describe our system architecture, road network model, problem definition, and the objectives of the paper. Table 1 summarizes the notation used in the paper.

3.1 System architecture

Figure 2 depicts the system architecture that consists of three entities: users, an LBS provider, and a Web mapping service provider (e.g., Google Maps). Users send shortest travel-time route (or path) *queries* with query origins and destinations to the LBS provider,

Table 1 Summary of notation

Notation	Meaning
$G = (V, E)$	a road graph G with node (intersection) set V and edge (segment) set E
$q_i = (o_i, d_i)$	a user's shortest travel-time path query q_i with origin o_i and destination d_i
$\mathcal{Q}$	a set of user queries
$R(o_i \rightarrow d_i)$	the shortest travel route from origin o_i to destination d_i
$l(a \rightarrow b)$	the travel distance from location a to location b
$t(a \rightarrow b)$	the travel time from location a to location b
$SA(R(o_i \rightarrow d_i), \mathcal{Q})$	the <i>sharing ability</i> of $R(o_i \rightarrow d_i)$ with respect to $\mathcal{Q}$
$R(o_i \rightarrow d_i) \subset R(o_j \rightarrow d_j)$	$R(o_i \rightarrow d_i)$ is the sub-route of $R(o_j \rightarrow d_j)$
$SA(R(o_i \rightarrow d_i), \mathcal{Q}) = -1$	$R(o_i \rightarrow d_i)$ is a sub-route of others
w_i	a waypoint
$\mathcal{W}$	an ordered waypoint set
m	the maximum number of waypoints in a route request
$G_w = (V_w, E_w)$	a weighted complete digraph G_w with node (waypoint) set V_w and edge (route) set E_w
O_w	a set of query origins
D_w	a set of query destinations
N_p	the number of parallel route requests submitted to the Web mapping service
$NDist(a \rightarrow b)$	the shortest network distance from location a to location b

where the origin could be a user's current location or any other location and the destination could be any POI or location that the user wants to go or is recommended by the LBS provider. Besides turning in its own business information to a querying user, the LBS provider also returns the detailed direction information of the shortest route based on the user selected travel model (e.g., driving, walking, or cycling), which is accessed from the Web mapping service provider through *external route requests*.

3.2 Road network model

In this paper, a road map is modeled as a graph $G = (V, E)$ comprising a set V of vertices with a set E of edges, where each road segment is an edge and each intersection of road segments is a vertex. For instance, Fig. 3a depicts a real road map that is modeled as an undirected graph (Fig. 3b), where an edge represents a road segment (e.g., $v_1 v_2$ and $v_1 v_5$) and a square represents an intersection of road segments (e.g., v_1 and v_2). As the weight of

Fig. 2 System architecture

Fig. 3 Road network model

each edge is static (i.e., the network distance), G cannot provide real-time travel-time-based route information.

3.3 Our problem and objectives

Given a set of user queries $\mathcal{Q} = \{q_1, q_2, \dots, q_n\}$ arrived concurrently or within a short time period at the LBS provider, and each user query q_i is in a form of (o_i, d_i) , where o_i and d_i are query origin and destination, respectively, the LBS provider returns the shortest travel-time route with the detailed direction information from o_i to d_i for each user query q_i based on live traffic conditions, which are retrieved from the Web mapping service provider through external route requests.

Since there are two critical limitations to access the travel route information from a Web mapping service as stated above, i.e., high cost and usage limits, our objectives are to reduce the number of external route requests issued by the LBS provider and the query response time to its users.

4 Direction sharing optimization

4.1 Optimal sub-route property

For an external route request with an origin and a destination, the Web mapping service will return the shortest travel-time route from the origin to the destination with detailed turn-by-turn direction information. For example, if the LBS provider sends an external route request to the Web mapping service to retrieve the travel route and time information from origin o_3

Fig. 4 Route information and sharing ability for $\mathcal{Q} = \{q_1, q_2, q_3, q_4, q_5, q_6\}$

(represented by a triangle) to destination d_3 (represented by a circle) as shown in Fig. 4a, the service returns $R(o_3 \rightarrow d_3) = \{\langle l(o_3 \rightarrow v_9), t(o_3 \rightarrow v_9) \rangle, \langle l(v_9 \rightarrow v_5), t(v_9 \rightarrow v_5) \rangle, \langle l(v_5 \rightarrow v_1), t(v_5 \rightarrow v_1) \rangle, \langle l(v_1 \rightarrow d_3), t(v_1 \rightarrow d_3) \rangle\}$, where $l(a \rightarrow b)$ and $t(a \rightarrow b)$ are the travel distance and time from location a to location b , respectively. For simplicity, we denote $R(o_3 \rightarrow d_3) = \{o_3 \rightarrow v_9 \rightarrow v_5 \rightarrow v_1 \rightarrow d_3\}$.

Shortest routes exhibit the optimal sub-route property [4], i.e., every sub-route of the shortest route is also the shortest sub-route (see Lemma 1). In other words, the shortest route $R(o_i \rightarrow d_i)$ returned from the Web mapping service for a query $q_i = (o_i, d_i)$ can be shared with another query $q_j = (o_j, d_j)$, if both o_j and d_j are located in the route,¹ i.e., $o_j \in R(o_i \rightarrow d_i)$ and $d_j \in R(o_i \rightarrow d_i)$; thus, there is no need for the LBS provider to issue an external route request for $q_j = (o_j, d_j)$ any more. As a result, the number of external route requests can be reduced.

Lemma 1 (Optimal sub-route property) *Let $R(o_i \rightarrow d_i) = \{o_i \rightarrow \dots \rightarrow o_j \rightarrow \dots \rightarrow d_j \rightarrow \dots \rightarrow d_i\}$ be the shortest travel-time route for a query with origin location o_i to destination location d_i . $R(o_j \rightarrow d_j) = \{o_j \rightarrow \dots \rightarrow d_j\}$ is also the shortest travel-time route from o_j to d_j .*

Proof See the proof of Lemma 24.1 in [4]. □

For example, only one external route request is needed instead of three to access the travel route information for $q_1 = (o_1, d_1)$, $q_2 = (o_2, d_2)$, and $q_3 = (o_3, d_3)$, as the travel

¹ If $R(o_i \rightarrow d_i)$ is directional, o_j and d_j should locate in the route in order.

route information of q_1 (i.e., $R(o_1 \rightarrow d_1)$) and q_2 (i.e., $R(o_2 \rightarrow d_2)$) can be shared with q_3 (i.e., $R(o_3 \rightarrow d_3)$) to find their travel route information, as shown in Fig. 4a.

4.2 Sharing ability

4.2.1 Definition

To reflect the possibility of sharing the direction information of a route with others, we formally define its *sharing ability* as follows:

Definition 1 (Sharing ability) Let $\mathcal{Q}$ be a set of user queries, and $R(o_i \rightarrow d_i)$ be the shortest travel-time route from origin location o_i to destination location d_i . The *sharing ability* of $R(o_i \rightarrow d_i)$ with respect to $\mathcal{Q}$ (denoted as $SA(R(o_i \rightarrow d_i), \mathcal{Q})$) is the number of queries in $\mathcal{Q}$, where the direction information of $R(o_i \rightarrow d_i)$ can be shared with these queries, i.e.,

$$SA(R(o_i \rightarrow d_i), \mathcal{Q}) = |\{q_j = (o_j, d_j) \in \mathcal{Q} \mid R(o_j \rightarrow d_j) \subset R(o_i \rightarrow d_i)\}|. \quad (1)$$

As an example depicted in Fig. 4a, where $\mathcal{Q} = \{q_1, q_2, q_3, q_4, q_5, q_6\}$ and $R(o_1 \rightarrow d_1) \subset R(o_2 \rightarrow d_2) \subset R(o_3 \rightarrow d_3)$, i.e., three queries (q_1, q_2, q_3) in $\mathcal{Q}$ can share the direction information of $R(o_3 \rightarrow d_3)$, the sharing ability of $R(o_3 \rightarrow d_3)$ with respect to $\mathcal{Q}$ is 3, i.e., $SA(R(o_3 \rightarrow d_3), \mathcal{Q}) = 3$. Since q_1 and q_2 can share the direction information of $R(o_3 \rightarrow d_3)$, we set the value of $SA(R(o_1 \rightarrow d_1), \mathcal{Q})$ and $SA(R(o_2 \rightarrow d_2), \mathcal{Q})$ to -1 as a flag to show that there is no need to compute them any more. Similarly, we can compute the sharing ability of q_4, q_5 and q_6 , which are shown in Fig. 4b. Therefore, three external route requests are needed to access the direction information for all the queries in $\mathcal{Q}$ instead of six.

Since the sharing ability can reflect the possibility of sharing the direction information of a route with others, to minimize the query response time to users and the number of external route requests, the LBS provider should process queries in $\mathcal{Q}$ in a non-increasing order based on their sharing abilities to fully utilize the direction sharing optimization. In the running example, the query answer of three queries (i.e., q_1, q_2, q_3) can be retrieved at the same time if q_3 is processed first, while only one query answer can be retrieved if q_6 is the first to be processed.

4.2.2 Calculation

However, the current direction information between two locations is unknown until the LBS provider issues an external route request to the Web mapping service and gets the result. Only knowing the road network model G and the origins and destinations of queries in $\mathcal{Q}$, it would be impossible to calculate the exact sharing ability of a route.

To this end, we plan to utilize historical route information (as [16, 29]), which are stored in the local database at the LBS provider when retrieved from the Web mapping service, to approximately reflect current route information and then compute route sharing abilities. Only when there is no historical direction information of a route in the local database, we calculate it based on the road network model G by employing Dijkstra algorithm (or A^* algorithm). For example, $R(o_3 \rightarrow d_3)$ can be accessed from the local database if there is historical direction information from v_{13} to v_2 , i.e., $v_{13} \rightarrow v_9 \rightarrow v_5 \rightarrow v_1 \rightarrow v_2$; otherwise, we compute the shortest network distance path from o_3 to d_3 based on G , and take the path as $R(o_3 \rightarrow d_3)$.

4.2.3 Algorithm

Algorithm 1 depicts the pseudo code of computing the sharing ability of the route from origin o_i to destination d_i . $R(o_i \rightarrow d_i)$ is retrieved from the historical route information in local database or computed based on G first. Then, for each query $q_j = (o_j, d_j)$ in $\mathcal{Q}$, if both o_j and d_j locate in $R(o_i \rightarrow d_i)$, the sharing ability of $R(o_i \rightarrow d_i)$ with respect to $\mathcal{Q}$ is increased by one based on Definition 1, and the sharing ability of $R(o_j \rightarrow d_j)$ with respect to $\mathcal{Q}$ is set to -1 as a flag to show that there is no need to compute it any more.

Algorithm 1 Sharing ability calculation for a route

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1: input: origin  $o_i$  and destination  $d_i$ , query set  $\mathcal{Q}$ , road graph  $G$ 
2:  $SA(R(o_i \rightarrow d_i), \mathcal{Q}) \leftarrow 0$ ;
3: Compute  $R(o_i \rightarrow d_i)$  based on historical route information or  $G$ ;
4: for each  $q_j = (o_j, d_j)$  in  $\mathcal{Q}$  do
5:   if both  $o_j$  and  $d_j$  locate in  $R(o_i \rightarrow d_i)$  then
6:      $SA(R(o_i \rightarrow d_i), \mathcal{Q}) ++$ ;
7:      $SA(R(o_j \rightarrow d_j), \mathcal{Q}) \leftarrow -1$ ;
8:   end if
9: end for
10: return  $SA(R(o_i \rightarrow d_i), \mathcal{Q})$ ;

```

4.3 Parallel processing for independent routes

Web mapping services can handle a large number of route requests at the same time; hence, another good way to further reduce the user query response time is the LBS provider issues external route requests to the Web mapping service in parallel. In order not to bring in additional requests to Web mapping services, route requests issued in parallel should be independent with each other (see Definition 2).

In the running example, the routes of q_3 and q_4 are independent. However, the routes of q_2 and q_3 are not, and an extra route request is needed if the routes of q_2 and q_3 are retrieved at the same time.

Definition 2 (Independent routes) Two routes $R(o_i \rightarrow d_i)$ and $R(o_j \rightarrow d_j)$ are independent if they are not the sub-route of each other, i.e., $R(o_i \rightarrow d_i) \not\subset R(o_j \rightarrow d_j)$ and $R(o_j \rightarrow d_j) \not\subset R(o_i \rightarrow d_i)$.

Definition 3 (Independent queries) Queries are independent if their querying routes are independent with each other.

To this end, independent queries (see Definition 3) in $\mathcal{Q}$ should be found for parallel processing. In fact, those independent queries have been detected out after the calculation of sharing ability, i.e., queries are independent if their sharing abilities are not equal to -1 (see Lemma 2).

Lemma 2 Given a user query set $\mathcal{Q}$, $\forall q_i, q_j \in \mathcal{Q}$, if both $SA(R(o_i \rightarrow d_i), \mathcal{Q}) \neq -1$ and $SA(R(o_j \rightarrow d_j), \mathcal{Q}) \neq -1$, then $R(o_i \rightarrow d_i)$ and $R(o_j \rightarrow d_j)$ are independent, where $R(o_i \rightarrow d_i)$ and $R(o_j \rightarrow d_j)$ are the querying route of q_i and q_j , respectively.

Proof As presented in Section 4.2, $SA(R(o_i \rightarrow d_i), \mathcal{Q}) \neq -1$ means $R(o_i \rightarrow d_i)$ is not the sub-route of any other querying routes, i.e., $R(o_i \rightarrow d_i) \not\subset R(o_j \rightarrow d_j)$. Similarly, $R(o_j \rightarrow d_j) \not\subset R(o_i \rightarrow d_i)$. Based on Definition 2, $R(o_i \rightarrow d_i)$ and $R(o_j \rightarrow d_j)$ are independent. $\square$

Take Fig. 4 for example, the routes of q_3 , q_4 and q_6 are not the sub-route of any other querying routes, so they are independent with each other and can be retrieved at the same time by the LBS provider with three external route requests.

5 Route waypoint optimization

5.1 Definition

Most of existing Web mapping services support adding multiple waypoints in a route request. Waypoints alter a route by routing it through the specified locations (see Definition 4). However, most of queries issued by users only seek for the shortest travel-time route information from their own origins to corresponding destinations, i.e., only two waypoints, which is less than the maximum allowed number of waypoints provided by Web mapping service providers (see Table 2). For example, Google Maps allows up to 8 intermediate waypoints in a route request for evaluation users and 23 intermediate waypoints for premier users [9]. On the other hand, there is usually a limit or charge on the number of route requests to a Web mapping service.

Definition 4 (Waypoint) A waypoint is a specified location that is used for navigation purposes. Given a route request with a set of ordered waypoints $\mathcal{W} = \{w_1, w_2, \dots, w_m\}$, where w_1 and w_m are the origin and destination locations, respectively, and the others are intermediate locations, the Web mapping service will return the detailed direction information from w_1 to w_2 to $\dots$ to w_m as a result for the route request, i.e., $R(w_1 \rightarrow w_2 \rightarrow \dots \rightarrow w_m)$, and the sub-route $R(w_i \rightarrow w_{i+1})$ ($1 \leq i \leq m-1$) between any two successive waypoints in the result.

Table 2 The maximum number of waypoints in a route request supported by three popular Web mapping services (Accessed on August 7, 2016)

Web mapping services	No. of waypoints
Google Maps for evaluation users	8
Google Maps for premier users	23
Bing Maps	25
MapQuest Maps	50

It is unwise for the LBS provider to simply issue external route requests to the Web mapping service provider for each query in $\mathcal{Q}$ separately without utilizing waypoints. Thus, a more efficient way is composing multiple independent user queries in $\mathcal{Q}$ as one external route request by taking the origins and destinations of those queries as waypoints.

For the example depicted in Fig. 4, processing each query in $\mathcal{Q}$ separately by using the direction sharing optimization requires three external route requests, as discussed in Section 4.3. Only one request with ordered waypoints $\mathcal{W} = \{o_3, d_3, o_6, d_6\}$ is needed to access the travel route information for all the queries in $\mathcal{Q}$. This is because the returned route $R(o_3 \rightarrow d_3 \rightarrow o_6 \rightarrow d_6)$ consists of $R(o_3 \rightarrow d_3)$, $R(d_3 \rightarrow o_6)$ and $R(o_6 \rightarrow d_6)$, which can be used for the query answers of $q_1q_2q_3$, q_4q_5 , and q_6 , respectively.

5.2 Problem modeling

To minimize the number of external route requests, the LBS provider should make full utilization of the direction sharing and waypoints provided by Web mapping services. The optimal ordered waypoint set $\mathcal{W} = \{w_1, \dots, w_m\}$ should be determined for an external route request to maximize the possibility of sharing its direction information with other queries in $\mathcal{Q}$, where m is the maximum number of waypoints in a route request supported by Web mapping services. In other words, we should maximize the sharing ability of $R(w_1 \rightarrow \dots \rightarrow w_m)$ with respect to $\mathcal{Q}$ by maximizing the sharing ability of the sub-routes in $\mathcal{W}$ with respect to $\mathcal{Q}$; hence,

$$SA(R(w_1 \rightarrow \dots \rightarrow w_m), \mathcal{Q}) = \sum_{i=1}^{m-1} SA(R(w_i \rightarrow w_{i+1}), \mathcal{Q}). \quad (2)$$

To find the optimal $R(w_1 \rightarrow \dots \rightarrow w_m)$, we first model the origins and destinations of the independent queries in $\mathcal{Q}$ and all routes between them as a weighted complete digraph $G_w = (V_w, E_w)$ comprising a set V_w of vertices, and a set E_w of weighted directed edges. The set V_w is composed by origins and destinations of all independent queries in $\mathcal{Q}$. The set E_w consists of directed routes between every pair of distinct vertices in V_w . The weight of each edge in E_w is represented by the sharing ability of its corresponding route, i.e., $weight(v_i v_j) = SA(R(v_i \rightarrow v_j), \mathcal{Q})$ ($v_i, v_j \in V_w$).

After modeling the independent queries in $\mathcal{Q}$ as a weighted complete digraph $G_w = (V_w, E_w)$, we should find a waypoint set $\mathcal{W} = \{w_1, \dots, w_m\}$ for $\mathcal{Q}$ such that the route $R(w_1 \rightarrow \dots \rightarrow w_m)$ will result in the best sharing ability. We can transform this problem into how to find a simple path in G_w with the largest weight via at most m vertices, which is a MAX SNP-hard problem (see Lemma 3), i.e., there is no polynomial-time algorithm that can even find a constant factor approximation for the problem unless $P = NP$ [13].

Lemma 3 *Finding a simple path in a weighted complete digraph $G_w = (V_w, E_w)$ with the largest weight via at most m vertices is a MAX SNP-hard problem.*

Proof Consider a special case of the problem: set the value of m to the number of vertices in G_w , i.e., $m = |V_w|$. Under this condition, the problem is reduced to the maximum-

weight traveling-salesman (Max TSP) problem, also known informally as the taxicab rip-off problem, which is a MAX SNP-hard problem [10]. Thus, the lemma is proved. $\square$

5.3 Waypoint selection

In this work, we aim to find the best set of waypoints in an external route request for all the queries in $\mathcal{Q}$ by designing a greedy algorithm with performance guarantee. The algorithm guarantees that at least $\lfloor \frac{m}{2} \rfloor$ queries in $\mathcal{Q}$ can share the direction information of the returned route from Web mapping services, which is specified by the selected waypoints, and tries to maximize the direction sharing power of the route at the same time. The details of the greedy algorithm are as follows.

5.3.1 The greedy algorithm

Given a query set $\mathcal{Q}$ and the maximum number of waypoints m , Algorithm 2 depicts the pseudo code of a greedy algorithm for finding the best waypoint set $\mathcal{W}$ for an external route request. It consists of three main steps:

Step 1: Preparation Initially, the waypoint set $\mathcal{W}$, the origin set O_w (for storing query origin location o_i), and the destination set D_w (for storing query destination location d_i) are set to empty. For each query $q_i = (o_i, d_i)$ in $\mathcal{Q}$, the sharing ability of its querying route with respect to $\mathcal{Q}$ (i.e., $SA(R(o_i \rightarrow d_i), \mathcal{Q})$) is calculated by Algorithm 1. Then, the query origins and destinations of independent routes (i.e., $SA(R(o_i \rightarrow d_i), \mathcal{Q}) > 0$, based on Lemma 2) are inserted into O_w and D_w , respectively. (Lines 3 to 13 in Algorithm 2)

Step 2: Initial waypoint selection In this step, the origin o_l and destination d_l of the query q_l with the largest sharing ability are selected. o_l is inserted into $\mathcal{W}$ as the first waypoint, and it is removed from O_w . If the number of waypoint in $\mathcal{W}$ (i.e., $|\mathcal{W}|$) is less than m , d_l is also inserted into $\mathcal{W}$ as the second waypoint and removed from D_w . The algorithm proceeds to the next step if $|\mathcal{W}| < m$ and O_w is not empty. (Lines 15 to 19 in Algorithm 2)

Step 3: Greedy waypoint selection In this step, d_l is the *last* waypoint inserted into $\mathcal{W}$. The next waypoint o_t is selected from all the origins in O_w such that $R(d_l \rightarrow o_t \rightarrow d_t)$ has the highest sharing ability. If the locations of d_l and o_t are the same, there is no need to insert o_t into $\mathcal{W}$ anymore, as d_l not only is the query destination of q_l , but also can be taken the query origin of q_t . For each independent query $q_i = (o_i, d_i)$ in $\mathcal{Q}$, if both o_i and d_i locate in $R(d_l \rightarrow o_t)$, i.e., $R(o_i \rightarrow d_i) \subset R(d_l \rightarrow o_t)$, o_i and d_i are removed from O_w and D_w , respectively, as the retrieved direction information of $R(d_l \rightarrow o_t)$ may be utilized as the answer of q_i . If $|\mathcal{W}| < m$, the corresponding destination d_t of o_t is also added to $\mathcal{W}$ and removed from D_w . This step is repeated until $|\mathcal{W}| = m$ or both the origin and destination sets (i.e., O_w and D_w) become empty. (Lines 21 to 41 in Algorithm 2)

Algorithm 2 The greedy algorithm of the route waypoint selection for a route request

```

1: input: query set  $\mathcal{Q}$ , the maximum number of waypoints  $m$ 
2: //Step 1: Preparation
3:  $\mathcal{W} \leftarrow \emptyset$ ;  $O_w \leftarrow \emptyset$ ;  $D_w \leftarrow \emptyset$ ;
4: for each  $q_i = (o_i, d_i)$  in  $\mathcal{Q}$  do
5:   if  $SA(R(o_i \rightarrow d_i), \mathcal{Q}) \neq -1$  then
6:     Calculate  $SA(R(o_i \rightarrow d_i), \mathcal{Q})$  by Algorithm 1;
7:   end if
8: end for
9: for each  $q_i = (o_i, d_i)$  in  $\mathcal{Q}$  do
10:  if  $SA(R(o_i \rightarrow d_i), \mathcal{Q}) > 0$  then
11:    Insert  $o_i$  into  $O_w$  and  $d_i$  into  $D_w$ ;
12:  end if
13: end for
14: //Step 2: Initial waypoint selection
15:  $SA(R(o_l \rightarrow d_l), \mathcal{Q}) \leftarrow \max\{SA(R(o_i \rightarrow d_i), \mathcal{Q}) \mid q_i \in \mathcal{Q}\}$ ;
16: Insert  $o_l$  into  $\mathcal{W}$  and remove  $o_l$  from  $O_w$ ;
17: if  $|\mathcal{W}| < m$  then
18:   Insert  $d_l$  into  $\mathcal{W}$  and remove  $d_l$  from  $D_w$ ;
19: end if
20: //Step 3: Greedy waypoint selection
21: while  $|\mathcal{W}| < m$  and  $O_w \neq \emptyset$  do
22:   for each  $o_i$  in  $O_w$ 
23:     Calculate  $SA(R(d_l \rightarrow o_i), \mathcal{Q})$ ;
24:   end for
25:    $SA(R(d_l \rightarrow o_t \rightarrow d_t), \mathcal{Q}) \leftarrow \max\{SA(R(d_l \rightarrow o_i), \mathcal{Q}) + SA(R(o_i \rightarrow d_i), \mathcal{Q}) \mid o_i \in O_w, d_i \in D_w\}$ ;
26:   if  $o_t \neq d_l$  then
27:     Insert  $o_t$  into  $\mathcal{W}$ ;
28:   end if
29:   Remove  $o_t$  from  $O_w$ ;
30:   for each independent query  $q_i = (o_i, d_i)$  in  $\mathcal{Q}$  do
31:     if both  $o_i$  and  $d_i$  locate in  $R(d_l \rightarrow o_t)$  then
32:       Remove  $o_i$  from  $O_w$  and remove  $d_i$  from  $D_w$ ;
33:     end if
34:   end for
35:   if  $|\mathcal{W}| < m$  then
36:     Insert  $d_t$  into  $\mathcal{W}$  and remove  $d_t$  from  $D_w$ ;
37:   else
38:     break;
39:   end if
40:    $d_l \leftarrow d_t$ ;
41: end while
42: return  $\mathcal{W}$ ;

```

Based on Algorithm 2, we have the following lemma:

Lemma 4 *At least $\lfloor \frac{m}{2} \rfloor$ queries in $\mathcal{Q}$ can share the direction information of the returned route from Web mapping services specified by waypoints in $\mathcal{W}$ determined by Algorithm 2, where m is the maximum number of waypoints in a route request.*

Proof As shown in Lines 17 to 19 and Lines 35 to 39 of Algorithm 2, when a query origin o_i is selected into the waypoint set $\mathcal{W}$, its corresponding query destination d_i is also selected if o_i is not the last waypoint; therefore, at least $\lfloor \frac{m}{2} \rfloor$ pairs of query origins and destinations are in the returned route from Web mapping services specified by waypoints in $\mathcal{W}$. Thus, the lemma is proved. $\square$

In summary, even though Algorithm 2 cannot select optimal waypoints in a route request as the target problem is MAX SNP-hard based on Lemma 3, it still can guarantee that at least $\lfloor \frac{m}{2} \rfloor$ pairs of query origins and destinations are selected, i.e., at least $\lfloor \frac{m}{2} \rfloor$ queries in $\mathcal{Q}$ can be processed in one route request (see Lemma 4), and it tries to maximize the direction sharing optimization of the route at the same time.

5.3.2 Example

Table 3 gives an example of Algorithm 2 in detail, where $\mathcal{Q} = \{q_1, q_2, q_3, q_4, q_5, q_6\}$ (Fig. 4), and the maximum number of waypoints in an external route request is four, i.e., $m = 4$. When $|\mathcal{W}| = m$ or O_w and D_w becomes empty, the algorithm returns $\mathcal{W} = \{o_3, d_3, o_6, d_6\}$ and terminates here.

Table 3 Example of Algorithm 2 (input: $\mathcal{Q} = \{q_1, q_2, q_3, q_4, q_5, q_6\}$, $m = 4$)

Step	Lines	$\mathcal{W}$	O_w	D_w	d_l Checking/Actions
Step 1: Preparation	Lines 3 to 13	$\emptyset$	$\{o_3, o_4, o_6\}$	$\{d_3, d_4, d_6\}$	– Calculate the sharing ability of each query in $\mathcal{Q}$ (Fig. 4) $\Rightarrow q_3, q_4, q_6$ are independent $\Rightarrow$ their origins and destinations are inserted into O_w and D_w , respectively
Step 2: Initial waypoint selection	Lines 15 to 19	$\{o_3, d_3\}$	$\{o_4, o_6\}$	$\{d_4, d_6\}$	d_3 q_3 owns the largest sharing ability $\Rightarrow o_3$ and d_3 are selected into $\mathcal{W}$ and removed from O_w and D_w , respectively; $d_l = d_3$
Step 3: Greedy waypoint selection	Lines 21 to 29	$\{o_3, d_3, o_6\}$	$\{o_4\}$	$\{d_4, d_6\}$	d_3 Calculate that $SA(R(d_3 \rightarrow o_4), \mathcal{Q}) = 0$ and $SA(R(d_3 \rightarrow o_6), \mathcal{Q}) = 2 \Rightarrow SA(R(d_3 \rightarrow o_4 \rightarrow d_4), \mathcal{Q}) = 2 < SA(R(d_3 \rightarrow o_6 \rightarrow d_6), \mathcal{Q}) = 3$, and $o_6 \neq d_3 \Rightarrow o_6$ is inserted into $\mathcal{W}$ and removed from O_w
	Lines 30 to 34	$\{o_3, d_3, o_6\}$	$\emptyset$	$\{d_6\}$	d_3 Both o_4 and d_4 locate in $R(d_3 \rightarrow o_6) \Rightarrow o_4$ and d_4 are removed from O_w and D_w , respectively
	Lines 35 to 40	$\{o_3, d_3, o_6, d_6\}$	$\emptyset$	$\emptyset$	d_6 $ \mathcal{W} < 4 \Rightarrow d_6$ is insert into $\mathcal{W}$ and removed from D_w ; $d_l \leftarrow d_6$

6 Algorithm with the proposed optimizations

Algorithm 3 The algorithm with the optimizations of direction sharing, waypoint utilization and parallel requesting (DPW-SA)

```

1: input: query set  $\mathcal{Q}$ , the maximum number of waypoints  $m$ , the number of parallel route
   requests  $N_p$ 
2: while  $\mathcal{Q}$  is not empty do
3:   //Step 1: Waypoint selection
4:    $k = 1$ ;
5:   Lines 3 to 13 in Algorithm 2;
6:   while  $k \leq N_p$  and  $O_w \neq \emptyset$  do
7:      $\mathcal{W} = \emptyset$ ;
8:     Lines 15 to 41 in Algorithm 2;
9:      $\mathcal{W}_k = \mathcal{W}$ ;
10:     $k++$ ;
11:   end while
12:   //Step 2: Parallel requesting
13:    $N_p$  route requests are issued at the same time to retrieve the direction information
   of routes specified by waypoints in  $\mathcal{W}_1, \mathcal{W}_2, \dots, \mathcal{W}_{N_p}$ ;
14:   //Step 3: Direction sharing
15:   for each returned route  $R(w_1 \rightarrow w_2 \rightarrow \dots \rightarrow w_m)$  specified by waypoints in
    $\mathcal{W}_i (i = 1, \dots, N_p)$  do
16:     for each query  $q_j = (o_j, d_j)$  in  $\mathcal{Q}$  do
17:       if  $o_j$  and  $d_j$  are located in any  $R(w_x \rightarrow w_{x+1})$  for  $x = 1, \dots, m - 1$  then
18:         Use the retrieved direction information to answer  $q_j$ ;
19:         Remove  $q_j$  from  $\mathcal{Q}$ ;
20:       end if
21:     end for
22:   end for
23:   Insert newly arrived queries into  $\mathcal{Q}$ ;
24: end while

```

Algorithm 3 (denoted as DPW-SA) depicts the pseudo code of the algorithm with the optimizations of Direction sharing, Parallel requesting, and Waypoints selected based on the Sharing Ability, to minimize the number of route requests and the user query response time. The algorithm has the following three steps:

Step 1: Waypoint selection Algorithm 2 is only to find the best set of waypoints in one external route request. To support parallel requesting, Algorithm 3 extends Algorithm 2 by adding a while loop in it to determine a number of waypoint sets, i.e., $\mathcal{W}_1, \mathcal{W}_2, \dots, \mathcal{W}_{N_p}$, where N_p is the number of route requests submitted to Web mapping services at the same time. (Lines 4 to 11 in Algorithm 3)

Step 2: Parallel requesting Then, the LBS provider issues N_p route requests to Web mapping services at the same time to retrieve the direction information of those routes. Each route request is specified by each waypoint set $\mathcal{W}_i (1 < i < N_p)$. (Line 13 in Algorithm 3)

Step 3: Direction sharing When the direction information of a route request is returned, i.e., $R(w_1 \rightarrow w_2 \rightarrow \dots \rightarrow w_m)$, for each query $q_j = (o_j, d_j)$ in $\mathcal{Q}$, if both o_j and d_j are located in any $R(w_x \rightarrow w_{x+1})$ for $x = 1, \dots, m - 1$, the retrieved direction information can be used to answer q_j and q_j is removed from $\mathcal{Q}$. (Lines 15 to 22 in Algorithm 3)

The algorithm repeatedly deals with the remaining and newly arrived queries in $\mathcal{Q}$ until $\mathcal{Q}$ becomes empty.

7 Performance evaluation

7.1 The baseline approach

To the best of our knowledge, there is no other existing work about taking advantage of waypoints in route requests to reduce the number of external route requests and the query response time for shortest travel-time path query processing, except for our previous work [35].

In [35], waypoints are selected based on the network distance instead of sharing ability, e.g., the two initial waypoints o_l and d_l are selected based on $NDist(o_l \rightarrow d_l) = \max\{NDist(o_i \rightarrow d_i) \mid q_i \in \mathcal{Q}\}$, and the next waypoint o_t is selected based on $NDist(d_l \rightarrow o_t) = \max\{NDist(d_l \rightarrow o_i) \mid o_i \in O_w\}$, where $NDist(a \rightarrow b)$ stands for the shortest network distance from location a to location b ; therefore, independent queries in $\mathcal{Q}$ can not be found out only based on the network distance. Besides, parallel requesting are also not equipped in [35] for reducing the user query response time.

To this end, we extend the algorithm proposed in [35] with parallel requesting and take it as the baseline algorithm (denoted as DPW-ND) in this paper, to show the advantage of selecting waypoints based on sharing ability and parallel requesting for independent queries. Algorithm 4 depicts the pseudo code of DPW-ND.

In summary, DPW-ND takes advantages of Direction sharing, Parallel requesting for selected queries in $\mathcal{Q}$ based on the network distance, and Waypoints selected based on the Network Distance, while DPW-SA makes the full utilization of Direction sharing, Parallel requesting for independent queries in $\mathcal{Q}$, and Waypoints selected based on the Sharing Ability.

7.2 Evaluation model

7.2.1 Performance metrics

We evaluate the performance of the baseline approach (i.e., DPW-ND) and our proposed algorithm (i.e., DPW-SA) in terms of two metrics: (1) the average number of external route requests submitted to the Web mapping service per user query and (2) the average query response time per user query. The query response time of a query is the time from the time when the query is received by the LBS provider to the time when the answer is returned to

the querying user; thus, it includes the local CPU processing time, the waiting time at the LBS provider, the communication time between the LBS provider and the Web mapping service, and the remote processing time at the Web mapping service provider.

Algorithm 4 The baseline algorithm (extended version of the algorithm proposed in [35], denoted as DPW-ND).

```

1: input: query set  $\mathcal{Q}$ , the maximum number of waypoints  $m$ , the number of parallel route
   requests  $N_p$ 
2: while  $\mathcal{Q}$  is not empty do
3:   //Step 1: Waypoint selection
4:    $k = 1$ ;
5:    $\mathcal{W} \leftarrow \emptyset$ ;  $O_w \leftarrow \emptyset$ ;  $D_w \leftarrow \emptyset$ ;
6:   for each  $q_i = (o_i, d_i)$  in  $\mathcal{Q}$  do
7:     Insert  $o_i$  into  $O_w$  and  $d_i$  into  $D_w$ ;
8:   end for
9:   while  $k < N_p$  and  $O_w \neq \emptyset$  do
10:     $\mathcal{W} = \emptyset$ ;
11:     $NDist(o_l \rightarrow d_l) = \max\{NDist(o_i \rightarrow d_i) \mid q_i \in \mathcal{Q}\}$ ;
12:    Insert  $o_l$  into  $\mathcal{W}$  and remove  $o_l$  from  $O_w$ ;
13:    if  $|\mathcal{W}| < m$  then
14:      Insert  $d_l$  into  $\mathcal{W}$  and remove  $d_l$  from  $D_w$ ;
15:    end if
16:    while  $|\mathcal{W}| < m$  and  $O_w \neq \emptyset$  do
17:       $NDist(d_l \rightarrow o_t) = \max\{NDist(d_l \rightarrow o_i) \mid o_i \in O_w\}$ ;
18:      Insert  $o_t$  into  $\mathcal{W}$  and remove  $o_t$  from  $O_w$ ;
19:      if  $|\mathcal{W}| < m$  then
20:        Insert  $d_t$  into  $\mathcal{W}$  and remove  $d_t$  from  $D_w$ ;
21:      else
22:        break;
23:      end if
24:       $d_l = d_t$ ;
25:    end while
26:     $\mathcal{W}_k = \mathcal{W}$ ;
27:     $k++$ ;
28:  end while
29:  // Step 2: Parallel requesting step and Step 3: Direction sharing step are the
   same with that in Algorithm 3
30:  Lines 12 to 22 in Algorithm 3
31:  Insert newly arrived queries into  $\mathcal{Q}$ ;
32: end while

```

7.2.2 Experimental Settings

We evaluated the performance of DPW-ND and DPW-SA using Java with a real road network of Hennepin County, Minnesota, USA [30]. We selected an area of $8 \times 8 \text{ km}^2$ that contains 6,109 road segments and 3,593 intersections, and the latitude and longitude of its left-bottom and right-top corners are (44.898441, -93.302791) and (44.970094, -93.204015), respectively.

Unless mentioned otherwise, Bing Maps is taken as the Web mapping service in our experiments, the number of waypoints is 10, and the number of route requests submitted to the Web mapping service in parallel is 50, i.e., $m = 10$, $N_p = 50$. The default number of user queries in our experiment is set to 1000, i.e., $|\mathcal{Q}| = 1000$: the query origins are generated following Gaussian($\sigma = 3$, $\beta = 10$) distribution, i.e., 10 Gaussian bells are generated in the road network, the standard deviation of each Gaussian bell is set to 3, and the number of query origins in those bells follow Zipf's law, to simulate user query origins more real [1, 16]; the query destinations are randomly selected from a real POI dataset (including 61 bars, 65 cafes, 320 restaurants, and 619 stores), which is collected from Google Places API [28] within the selected area.

7.3 Experimental results

We evaluate the scalability, efficiency, and applicability of the proposed algorithm (i.e., DPW-SA) and the baseline approach (i.e., DPW-ND) with respect to various numbers of queries, waypoints and parallel route requests, as well as different query distributions.

7.3.1 Effect of the number of queries

In this section, the number of user queries varies from 400 to 2,000 to evaluate the performance of DPW-ND and DPW-SA with respect to various numbers of queries as depicted in Fig. 5.

Without any optimization, the LBS provider needs to issue one external route request for each query. With the utilization of waypoints in a route request, only 0.2 route request per user query is needed if the number of waypoints is 10. With the optimization of waypoints and direction sharing, DPW-ND can reduce the average number of route requests by at least 20 %, i.e., less than 0.16 route request per user query is needed; while, DPW-SA can further reduce it by nearly 22 % on average compared with DPW-ND, which benefits from selecting waypoints based on sharing ability and parallel requesting for independent queries (Fig. 5a).

When the number of queries gets larger, there are more outstanding queries in the road network; hence, the direction information of a route has a higher chance to be shared with more queries (i.e., the power of the direction sharing optimization increases); thus, the number of external route request gets lower for both evaluated algorithms, as show in Fig. 5a. The results also show the scalability of DPW-SA with the increase of the number of queries.

As the default number of parallel route requests submitted to the Web mapping service is fixed, i.e., $N_p = 50$, when there are more queries arrived, a query encounters a longer waiting time. Therefore, the average query response time gets longer with the increase of the

Fig. 5 Effect of the number of queries

number of queries, as depicted in Fig. 5b. DPW-SA yields the less average query response time compared with the baseline algorithm DPW-ND, i.e., 12 % reduced.

7.3.2 Effect of the number of waypoints in an external route request

In this section, the number of waypoints provided by the Web mapping service provider varies from 2 to 20, to study the performance of DPW-ND and DPW-SA with respect to various numbers of waypoints, as depicted in Fig. 6.

With more waypoints utilized in an external route request, its direction information can be used to answer more queries. Therefore, when the number of waypoints gets larger, the average number of external route requests for DPW-ND and DPW-SA drops significantly (Fig. 6a). Figure 6a also shows that DPW-SA is more effective with different numbers of waypoints as it consistently yields less external requests than DPW-ND. Similarly, the average query response time of DPW-ND and DPW-SA drops gradually along with the increase of the number of waypoints (Fig. 6b). As a result, our DPW-SA can achieve not only the best number of external route requests (20 % reduced on average) but also the shortest query response time (13 % reduced on average) compared with DPW-ND.

7.3.3 Effect of the number of parallel route requests submitted to the web mapping service

In this section, the number of parallel route requests submitted to the Web mapping service varies from 10 to 100, to study the performance of DPW-ND and DPW-SA with respect to various numbers of parallel route requests, as depicted in Fig. 7.

The number of external route requests of DPW-ND and DPW-SA increases when the number of parallel requests gets higher (Fig. 7a). This is because they issue more parallel route requests for queries in Q that will weaken the sharing power of the direction sharing optimization. It is expected that when the system is able to send more parallel route requests, it achieves a better query response time (Fig. 7b). Still, DPW-SA performs much better than DPW-ND in terms of the number of external route requests (23 % reduced on average) and the query response time (14 % reduced on average).

7.3.4 Effect of different query distribution

In this section, we conduct two sets of experiment to study the performance of DPW-ND and DPW-SA with respect to different query distribution. For each query distribution $G(\sigma, \beta)$,

Fig. 6 Effect of the number of waypoints in an external route request

Fig. 7 Effect of the number of parallel route requests

we select β Gaussian bells in the road network randomly, set the standard deviation of each Gaussian bell to σ , and generate 1,000 query origins in those bells follow Zipf's law [1], while the query destinations are randomly selected from a real POI dataset.

For one set of experiment, the number of Gaussian bells varies from 1 to 20, and the standard deviation of each Gaussian bell is set to 3, as shown in Fig. 8. When the number of Gaussian bells increases, queries get more and more disperse in the road network, which weakens the sharing power of the direction sharing optimization; thus, the number of external route requests of DPW-ND and DPW-SA increases, resulting in the increase of the query response time accordingly.

For the other set of experiment, the number of Gaussian bells is set to 10, and the standard deviation of each Gaussian bell varies from 1 to 10, as shown in Fig. 9. Besides, we also generate query origins uniformly for comparison. When the standard deviation gets smaller, i.e., queries are more near to each other, queries selected by DPW-ND for parallel requesting are more 'dependent' with each other as DPW-ND selects them only based on the network distance, which leads to more unnecessary route requests are issued; therefore, both the number of external route requests and the query response time of DPW-ND is the highest when the standard deviation is the smallest. Such situation will not happen to DPW-SA, since it selects queries for parallel requesting based on the sharing ability, i.e., independent queries are selected.

Observe that no matter any Gaussian distribution or Uniform distribution, our DPW-SA outperforms DPW-ND on both the number of external route requests (26 % reduced on average) and the query response time (15 % reduced on average).

Fig. 8 Effect of different query distribution (with different number of Gaussian bells)

Fig. 9 Effect of different query distribution (with different standard deviation)

8 Conclusion

In this paper, we have proposed a spatial mashup framework for a location-based service (LBS) provider to retrieve travel route information between two location points in a road network through issuing an external route request to a Web mapping service, e.g., Google Maps, Bing Maps, and MapQuest Maps. Since retrieving external data is much more expensive than accessing local data, we employ the direction sharing, parallel requesting and route waypoint optimizations to reduce the number of such external route requests and the query response time for users. To reflect the possibility of sharing the direction information of a route, we first formally define a method to measure its sharing ability, and find out the queries that their querying routes are independent with each other for parallel processing. Then, we model the problem of selecting the optimal set of waypoints in a road network for an external route request, i.e., the sharing ability of the sub-routes in a route request should be maximized, as the problem of finding the longest simple path in a weighted complete digraph. As it is a MAX SNP-hard problem, i.e., there is no polynomial-time algorithm that can even find a constant factor approximation for the problem unless $P = NP$, we propose a greedy algorithm with performance guarantee to find the best set of waypoints in an external route request. We evaluate the performance of our algorithm using a real Web mapping service, a real road network, real and synthetic data sets. Our experimental results show that our proposed algorithm is efficient and scalable with various numbers of queries, waypoints and parallel route requests, as well as different query distributions.

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