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## From Routine To Better Network Services

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# De Routine à de Meilleurs Services de Réseau

Eduardo Mucelli Rezende Oliveira , Aline Carneiro Viana

**RESEARCH  
REPORT**

**N° 8451**

January 2014

Project-Teams





## De Routine à de Meilleurs Services de Réseau

Eduardo Mucelli Rezende Oliveira \*, Aline Carneiro Viana \*

Équipes-Projets

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**Résumé :** Dans ce travail, nous évaluons le comportement routinière des gens et soulignons moyens de l'explorer afin de fournir de meilleurs services de réseau. Nous avons étudié deux ensembles de données réelles représentant ensemble plus de 6 ans de trajectoires de vie quotidienne. Les résultats montrent en effet que les gens ont tendance à prendre les chemins les plus courts quel que soit le mode de transport. En outre, c'est le comportement collectif, pas le comportement d'un certain groupe de personnes. Enfin, les personnes montrent plusieurs caractéristiques sur leurs habitudes de mobilité: trajectoires confinées et très répétitives. Nous avons alors présenté plusieurs scénarios dans lesquels des solutions de réseau peuvent être fournies en profitant de ces comportements et des façons de les aborder.

**Mots-clés :** routine, réseaux, services de réseau

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## From Routine To Better Network Services

**Abstract:** In this work, we assess the routinary behavior of people and point out means to explore it in order to provide better network services. We have studied two real datasets representing together more than 6 years of trajectories from people's daily lives. The results show that people indeed tend to take shortest paths regardless the transportation mode. Furthermore, it is a collective behavior, not a specific behavior of a certain group of people. Finally, people demonstrate more two characteristics on their mobility patterns: highly confined and repetitive trajectories. We have then presented several scenarios in which network solutions might be provided taking advantage of those behaviors and some ways to approach them.

**Key-words:** routine, networks, network services

## 1 Introduction

People are routinary semi-rational entities, they have regular circles of actions guided by their decisions but unexpected situations may interfere on their directions [1]. A person may change their itinerary due to a traffic jam, problems on the public transportation, etc. When choosing an itinerary, people tend to use the shortest-path to reach their destination, also known as "*desire line*". The desire line is the shortest path between origin and destination, and expresses the way a person would like to go, if such a way were available [2]. Furthermore, the people's itinerary is characterized by its *confinement*, i.e., despite of choosing the shortest-paths, people will roam repetitively close by their main physical address [3].

Social ties among users have been widely exploited in opportunistic mobile networks to favor network services [4, 5]. Nevertheless, still few works have been investigating user mobility in terms of their trajectories and daily space-time routines. On the other hand, we are going to assess the trajectories that people produce on their daily activities in two cities counting more than 2200 days span in order to understand how short and routinary the routes are.

To accomplish our objective, we study real-life mobility traces (cf. Section 3) of people in two metropolitan areas, namely Beijing and Tokyo, and measure two key characteristics of their routines, Confinement (cf. Section 3.3) and Shortest-paths (cf. Section 3.4). Results reveal that 83% and 95% of the trajectories for Beijing and Tokyo, respectively have, at most, 10 km maximum displacement, i.e., people have their mobility confined. Furthermore, results show that, on average, 70% of the trajectories are, at most, half longer than the shortest path regardless of the transportation mode. Section 4 discusses some scenarios in which network solutions might take advantage of daily trajectories based on the measurements herein presented in order to provide people with better network services. Finally, Section 5 concludes this work.

## 2 Related Work

Human mobility has been widely studied, mainly focusing on the relation between people. Remarkably, [6] studied the implication of mobility on how separated people are and concluded that, in United States, people seemed to be separated by three acquaintance links.

More recently, the shortness of displacement was assessed by analysing the circulation of bank notes in the United States [3]. From a total of 20,540 short-time trajectories originating across the United States, results for three major cities, namely Seattle, New York, Jacksonville, shown that the probability of a trajectory measuring less than 10 km were 57.7%, 57.7% and 71.4%, respectively. On contrary to bank notes, our data is represented by GPS tracks which seems to be one of the most accurate ways to track mobility of people.

Regarding routinary visit of places, [7] proposed a solution to identify points of interest based on people's mobility characteristics. Our work differs since we are not interested on the points of interest but on the routinary characteristics present on people's trajectories.

## 3 Evaluation

To assess the routinary characteristics on people's daily lives we have used two datasets describing mobility on two big metropolitan areas, Beijing and Tokyo. The following subsections describe their characteristics.

### 3.1 Datasets

In this work, we are using two datasets, GeoLife on its latest version [8] and a crawled dataset from OpenStreetMap [9]. GeoLife is considered to be unique in the literature. This is due to the fact that it provides a rich view of people mobility using 11 different transportation modes in an urban area for a long period of time. It provides geolocalized and timestamped points from 182 people during spread on 1600 days, from April 2007 to October 2011, mostly in Beijing. OpenStreetMap is collaborative open geodata online map that started in 2008 and currently has more than 1.3 million registered users. On OpenStreetMap, an user may upload his GPS tracks using GPX format that describes his geolocalized coordinates during the time. From it we have crawled user GPS tracking data from several cities using their API<sup>1</sup>. From this set we have chosen to use a subset containing information from users in Tokyo, one of the biggest cities in terms of available data. Tokyo dataset contains 88 people during 606 days from August 2007 to September 2013.

For each person, both datasets provide a set of geolocalized points, i.e., a GPS trajectory ascendingly sorted by timestamp. Trajectory represents how people moves around and is described as a set of points representing GPS coordinates periodically collected. In GeoLife dataset, people may move around building their trajectories using at most ten different transportation modes such as taxi, bike, run, bus, walk, train, subway, car, boat, and motorcycle. It is important to enhance that transportation mode information is not available for all trajectories on GeoLife and it is not available at all in Tokyo dataset. When it comes to assess mobility of people, the transportation mode is an important information. Indeed, transportation mode could change completely the network demands coming from people's devices : e.g., a person riding a bike has a different context than someone inside a bus, therefore, the former will be less susceptible to use the phone than the latter. In order to label the unlabeled trajectories, we have created a simple model that sets a transportation mode depending on the average speed in which the person is traveling. Section 3.2 describes in details how trajectory labeling was performed.

Moreover, to better understand specific behaviors inherent from different periods of the day, every day is divided into four periods of 6 hours, from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59.

### 3.2 Labeling

Not every trajectory from the datasets herein considered are labeled with transportation modes. That is due to the fact that labeling was not mandatory for people participating on the GeoLife experiment nor it is an expected information on OpenStreetMap GPS data. A trajectory may have at least one transportation mode label. Each subset of points with a unique transportation mode contained in a trajectory is called *leg*. For example, a trajectory composed by two legs, "car" and "walk" representing a situation in which a person went by car to his work, parked the car and went walking until his office.

Our model labels trajectories by their average speed, which is calculated considering both the length and the duration of the traveled leg. The result is matched against known speed ranges on the city. Table 1 describes average speed ranges by transportation mode in Beijing. We have used the same ranges to assign labels to the legs in Tokyo. Lets consider we have an unlabeled leg  $l$  traveled with average speed of 5  $m/s$ . Consulting the Table 1, it is possible to see that  $l$  falls on a range in which three transportation modes present overlapping average speed ranges, taxi, motorcycle, and car. Therefore, each one has equal chance of being chosen by a randomly

1. [http://wiki.openstreetmap.org/wiki/API\\_v0.6](http://wiki.openstreetmap.org/wiki/API_v0.6)

TABLE 1 – Average speed ( $m/s$ ) ranges by transportation mode

Transportation mode	Average speed range
Walk	$\leq 1.5$
Bus	$> 1.5$ and $\leq 4$ [10]
Bike or Run	$> 4$ and $\leq 4.4$ [11]
Taxi, Motorcycle, or Car	$> 4.4$ and $\leq 11.5$ [12]
Subway	$> 11.5$ and $\leq 28$ [13]
Train	$> 28$ and $\leq 250$
Airplane	$> 250$

uniformly distributed number. In this example,  $l$  will be labeled either as 'taxi', 'motorcycle', or 'car' with 33% of chance.

The transportation mode of a leg will be used to calculate its known shortest path. Therefore, in cases where labels are dividing a speed range, i.e., (1) 'bike' and 'run' and (2) 'taxi', 'motorcycle' and 'car', there is not negative impact on assigning a specific label instead of another in the same range. That is because the shortest path for labels in (1) is calculated differently for labels in (2) (cf. Section 3.4).

### 3.3 Confinement

To understand how the routine occurs on our scenario, we have measured how confined and repetitive the trajectories are.

In order to measure how confined are the trajectories, for each trajectory, we have calculated the maximum displacement, i.e., the distance between its initial and farthest point (not necessarily the last point). Fig. 1 presents the CCDF of the maximum displacement for all trajectories grouped by period on both datasets. It shows that 83% and 95% of the trajectories for Beijing and Tokyo respectively, have at most, 10 km maximum displacement and the period of the day does not affect this behavior. This result shows that generally people do not move far away from their starting point, and presents high confinement. Results shown in [3] reveal that the percentage of trajectories with displacement less than 10km ranged from 52% to 71%. GPS tracking seems to be one of the most accurate ways to track mobility of people. Therefore, we believe that the higher confinement presented in our results is a more precise measurement of human displacement on an urban scenario.

People with confined mobility tend to repetitively visit the same areas. To understand how people explore the regions, central Beijing and Tokyo were divided into square-shaped cells of 50  $m^2$  summing up 800 and 916 thousand cells, respectively. Then, we have calculated the number of unique cells ( $NUC$ ) and total cells ( $NTC$ ) that each trajectory visited. To quantitatively express the percentage of confinement of a trajectory, a metric called *Repetitiveness* was conceived and is represented as the following :  $\frac{NTC-NUC}{NTC} * 100$

Repetitiveness of a trajectory represents how repetitive is the route described by this trajectory. Regardless of the period of the day, trajectories present a considerable amount of repetitiveness on both datasets. In Beijing, 90%, 89%, 90% and 92% of the performed trajectories present at most 50% of repetitiveness (i.e., half of the cells are repetitively visited) for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59, respectively. Tokyo presents similar results, 98% 93% 94% 95% for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59, respectively. An interesting aspect of this results is to understand if the repetitiveness is related to the amount of trajectories per-



formed by people and possibly to the amount of visited cells : "*Does repetitiveness occurs less where less trajectories are performed?*". Revisiting areas is a consistent personal behavior that does not rely on the amount of trajectories that were performed on a certain period. In Beijing, both periods from 06 :00 to 11 :59 and from 00 :00 to 05 :59 have high and similar repetitiveness rates but the former has 6.4 times more trajectories than the latter. Similarly in Tokyo, period from 12 :00 to 17 :59 has 21 times more trajectories than the period from 00 :00 to 05 :59 but they present similar results.

On the other hand, repetitiveness also may be used to represent how repetitively a cell receives visits. The repetitiveness of a cell is based on the number of unique users (*NUU*) and total users (*NTU*) that visited it as following :  $\frac{NTU-NUU}{NTU} * 100$ . Fig. 2 (better seen in colors) shows a heatmap by period of the day colored by repetitiveness values of each cell. This result depicts that repetitiveness is power-law distributed throughout the cells, i.e., while most of the cells receive few visits, few cells receive most of the visits. Indeed, 78%, 77%, 77% and 87% of the cells in Beijing have, at most, 5% of repetitiveness (i.e., 5% of users revisited it) for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59, respectively. Besides, 0.4%, 0.2%, 0.2% and 0.2% of the cells in Beijing have more than 90% of repetitiveness for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59 respectively. People repetitively visit the same cells (high repetitiveness of trajectories shown previously), resulting in some few areas being highly popular, while most of the areas are unpopular. Regardless of the period of the day, a north central area consistently shows cells with high repetitiveness, which is due to the fact that Microsoft Research Asia headquarter is located there. GeoLife experiment was conducted mostly with Microsoft members that were constantly walking nearby the working place.

Tokyo presents similar results, 76%, 75%, 72%, and 83% of its cells have, at most, 5% of repetitiveness for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59, respectively. On the other hand, 0.1%, 0.8%, 0.2%, and 0.07% of the cells have more than 90% of repetitiveness for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59 respectively. Two remarkable areas are presented on Tokyo's heatmap : (1) Kodaira Train Station on the northwest presents high repetitive from 06 :00 to 11 :59 and (2) Motosumiyoshi Station on the south highly active from 06 :00 to 11 :59 and from 12 :00 to 17 :59. Both present the characteristic of big train stations, high repetitive values due to people going to and from their daily activities commuting in those station.

### 3.4 Shortest-paths

The concept of "desire lines" states that people tend to choose the shortest-paths to arrive on their destinations. In order to verify that, we have compared the length of each traveled leg against the length of the corresponding shortest path considering the same initial and final points of the original leg. Dividing the length of the original leg by the length of the shortest path allows us measuring how longer the path made by a person is from the shortest path. We have used Google Directions API<sup>2</sup> to compute the shortest path. The API receives the coordinates of both initial and final points and a *travel mode*, i.e., transportation mode. Then, it returns the shortest path considering the restrictions imposed by the existing routes and obstacles in the city for a specific transportation mode. Note that, we only have considered transportation modes where people have decision control of their paths. This excludes for example, buses, boats or trains.

Legs traveled by walking, running, and biking had their lengths divided by their respective shortest paths computed while using the API in *walking* mode. Google Directions API indeed has a *bicycling* travel mode, but at the moment, it does not contain routes neither in Beijing nor

2. <https://developers.google.com/maps/documentation/directions>

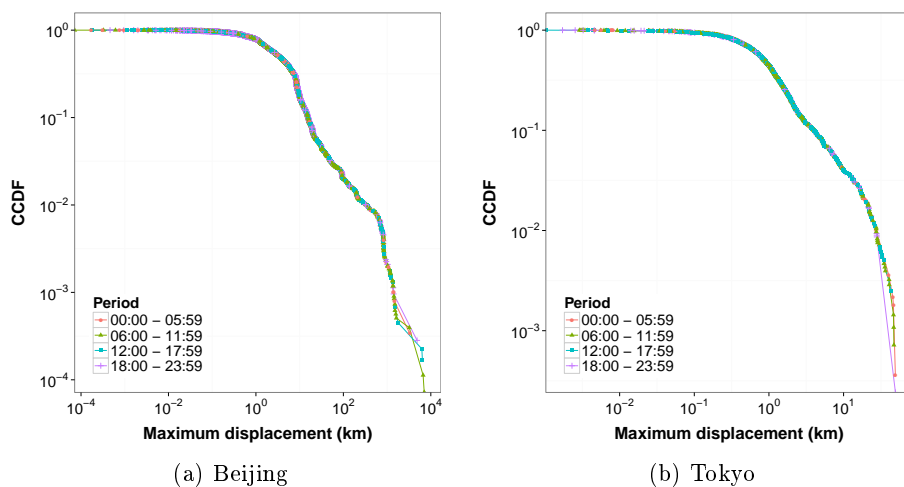


FIGURE 1 – CCDF of the maximum displacement.

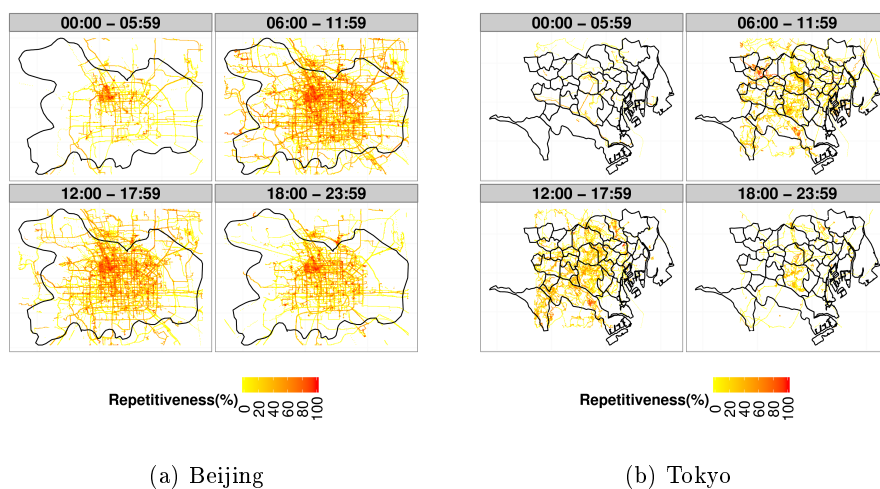


FIGURE 2 – Heatmap of the Repetitiveness by grid cell (better seen in colors).

in Tokyo. Legs traveled by taxi, car, and motorcycle had their lengths divided by results of the API in the *driving* mode. Fig. 3 shows the CCDF of the ratio between the original legs length and the Google shortest path, by transportation mode and period of the day.

For Beijing, it shows that the periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59 present, respectively, 60%, 72%, 65% and 79% of the legs measuring, at most, half longer than the shortest path. That results show that on late night people tend to walk around not directly going to their destination. Indeed, on late night people tend to go for bars, night clubs and are more susceptible to create routes that are way longer than the shortest ones. On the other hand, periods representing early morning and early night show high percentage of legs closest to the shortest one and describing how people go directly to their destinations, e.g., work, home, etc. The period containing the early afternoon hours present an intermediate percentage of legs close to the shortest path. Indeed, this period

mixes people walking around careless about shortest paths (e.g, someone shopping, or looking for restaurants), and people more concerned about their being on time (e.g, people coming back from the lunchtime towards the work). Moreover, it is possible to see that the length ratio does not change in function of the transportation mode. It shows that regardless of the transportation mode, people tend to be oriented by the shortest paths.

On the other hand, Tokyo presents 56%, 49%, 46% and 61% ratio for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59, respectively. Indeed, those values are smaller when compared with GeoLife results. That is due to the fact that 48% of days contained on OpenStreetMap dataset are on weekends, i.e., Saturday and Sunday, contrary to GeoLife that counts 27% of its days on weekends. Therefore, in this case, OpenStreetMap presents trajectories composed of mixed behaviors inherent from the differences between working days and weekend days, e.g., people performing short routes going straight to work and people making longer routes roaming around while shopping.

Finally, it is important to understand whether the legs with low length ratio are performed by a small group of people or throughout a large group, i.e., *"Is the usage of shortest paths an isolated tendency or a collective behavior?"*. To do so, we calculate, for each period of the day, the cumulative percentage of users. Length ratio values were taken in steps of 0.5. For each step, we calculate the percentage of users who performed, at least, 50% of legs shorter than the step. We calculate the percentage relative to the number of users on each period. Fig. 4 shows the cumulative percentage of users in function of the length ratio grouped by period of the day. For Beijing, it shows that 67%, 75%, 66%, and 77% percent of the users perform mostly legs that are, at most, half longer than the shortest ones respectively for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59. Finally, for the same metric Tokyo presents 43%, 60%, 35% and 72% for periods from 00 :00 to 05 :59, from 06 :00 to 11 :59, from 12 :00 to 17 :59, and from 18 :00 to 23 :59. Therefore, the usage of shortest paths is indeed a collective behavior.

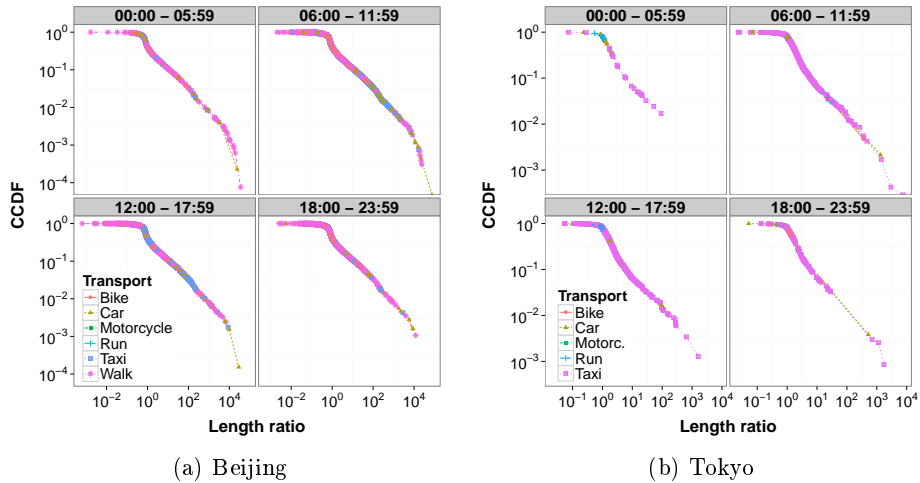


FIGURE 3 – CCDF of the length ratio by period.

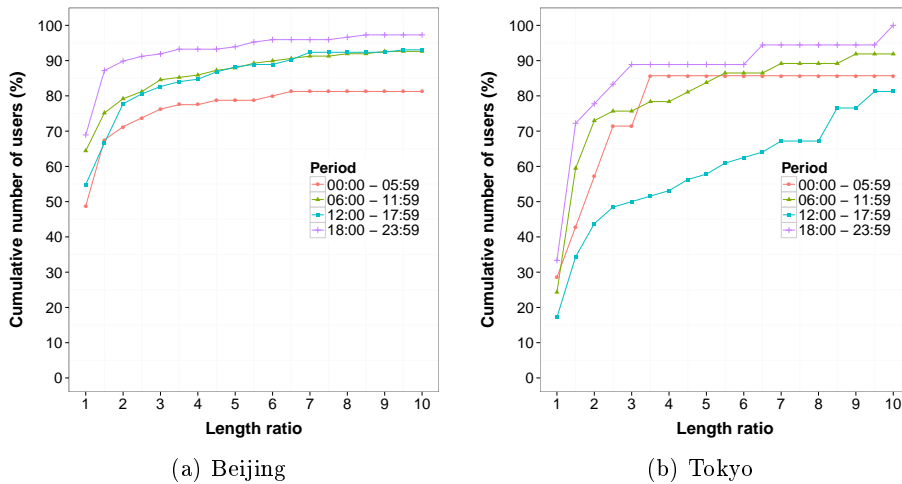


FIGURE 4 – Percent of users as a function of the length ratio by period.

## 4 Discussion

Understanding human mobility behavior is a key aspect to develop better network services and solutions on several areas. This section discusses some applications that may benefit from mobility aspects previously presented. Furthermore, GeoLife is a rich dataset suitable for studying routine-based services but has not been much explored in the literature. On the other hand, OpenStreetMap is still collaboratively building its GPS tracking dataset and it is not as rich as GeoLife in this aspect for any specific city.

**Forwarding Protocols** An important problem on Pocket Switched Networks area is how to couple human mobility patterns with message forwarding algorithms [14]. Routinary behavior has been widely studied when it comes down to encounters among nodes. On the other hand, trajectories behavior could be studied to improve protocols based on store-and-forward late delivery. How far a person routinely goes or how frequently one visits the same places in a city could be important characteristics to define the potential of a peer to be chosen to keep a message to be routed. For instance, the few percentage of people going routinely further than the 10km mark could be important routers on a Pocket Switched Network [15].

**Social Hotspot Deployment** Unplanned deployment of hotspots may lead to both under-utilized and over-utilized network areas. The expansion of metropolitan areas increased the possibility of moving around. This fact together with the increase of smartphone use results in highly dynamic links, which may significantly affect the performance of the network. Moreover, people may use different transportation modes, which significantly impacts their trajectories. Mobility-oriented deployment may be an important point while projecting a network deployment. For instance, areas in which people frequently visit during their routinary behavior may be used as key areas to deploy a complementary network, e.g., WiFi hotspots providing data-offloading points for a 3G network [16].

**Routine-based Data Prefetching** Prefetching has been shown to effectively reduce user perceived latency. An interesting approach might be to merge trajectory information with demanded

content in order to provide a smart data prefetching approach. Based on the routine of person, a prefetching service could, for example, store static content of web pages visited often. This content could be downloaded using access points present in the places routinely visited by the person. For instance, an application for mobile phones could download content in advance at home using WiFi and this would be later presented along with content downloaded using 3G in real time. This approach could alleviate the usage of 3G by shifting to inexpensive networks (such as WiFi) the load of static content such as images.

**Public Transportation Planning** Monitoring, distributing, and processing traffic information may enable better strategic planning and encourage better use of public transportation. Several applications may take advantage of the driver's routinary behavior in order to improve aspects of the Vehicular Networks. For instance, traffic information, e.g., accidents, construction sites, traffic jams may be exchanged between vehicles. On a routinary scenario, all those information may be used to forecast the situation for the next days and alert the driver, for example, about possible alternative roads. Besides, a service may identify points of interest based on driver's mobility patterns. Identify parking lots and its availability in number of spots, or suggest the best charging station for electrical vehicles based on the driver's routine and battery conditions. Furthermore, a service to advertise products on roadside signs may merge different sources of information in order to display targeted marketing. By crossing information from the driver's routinary trajectories, traffic condition and the driver's interests, a service could present ads that match driver's interest on a certain area of the city likely having the driver on its vicinity. On a collaborative scenario, a carpooling service could suggest people to get or to offer a ride based on regular driver's destinations and passengers interested on ride-sharing.

## 5 Conclusion

In this work, we have assessed the routinary behavior of people and pointed out means to explore it in order to provide better network services. We have studied a two real datasets representing together more than 2200 days from people's daily lives in Beijing and Tokyo. The results show that people indeed tend to take shortest paths regardless the transportation mode and that it is a collective behavior, not a specific behavior of a certain group of people. In addition, people demonstrate more two characteristics on their mobility patterns : highly confined and repetitive trajectories. For instance, 83% and 95% of the trajectories for Beijing and Tokyo respectively, have at most, 10 km maximum displacement regardless the period of the day. Besides, on average, 70% of the trajectories are, at most, half longer than the shortest path regardless of the transportation mode. We have also presented (1) several network scenarios which might take advantage of those behaviors and (2) some possible ways to provide better network services on such scenarios. As future work, we envision to study routine-based deployment solutions with the purpose of providing a data-offloading architecture.

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