Test Model and Coverage Analysis for Location-based Mobile Services

Tao Zhang
Department of software engineer
Northwest Polytechnical University
Xi'an, China
tao_zhang@nwpu.edu.cn

Jerry Gao
Department of software engineer
San Jose State University
San Jose, USA
jerry.gao@sjsu.edu

Oum-EI-Kheir Aktouf
LCIS University of Grenoble,
France
Oum-El-Kheir.Aktouf
@grenoble-inp.fr

Abstract—**Mobile Location-based services (LBS) have been considered as one kind of important mobile app services, which provide many interesting and convenient services based on mobile user positions. The availability and validity of mobile LBS are affected by mobile user location contexts, which make mobile LBS testing becomes one urgent and challenging issue. There are three major reasons contributing to this issue. They are: a) the large number of areas and various location contexts; b) millions of location objects with various information; c) mobile users with dynamic moving paths and patterns. This paper focuses on mobile LBS testing, especially on testing location-based mobile information services. A novel test object model is proposed for location-based mobile information services, and some test coverage metrics are also provided. The proposed test object model and coverage metrics help test engineers design test cases efficiently and effectively. Moreover, a case study is reported to demonstrate its potential application.**

Keywords-component; Location-based service; mobile app; mobile testing; test model; test coverage;

I. INTRODUCTION

In recent years, more and more diverse mobile applications (mobile apps) have been developed to support different applications in social, news, tourism, health, business, and other domains. Hundreds of new apps are released daily, *e.g.* about 300 new apps appear on Apple's App Store each day. In turn, 750 million Android and iOS apps are downloaded each week [1].

Mobile Location-based services are services enhanced with positional data, which are provided by mobile apps using GPS, digit maps, and other techniques [2]. Many mobile apps provide interesting and convenient location-based services and functions. The mobile app Yelp (www.yelp.com) recommend nearby shops, restaurants, *etc*. In the social network mobile app Loopt (www.loopt.com), the users receive notifications whenever their friends are nearby. The mobile app Waze (www.waze. com) reports nearby traffic jams, policemen, gas stations and friends.

LBS have been identified as the one of most important features of mobile app services [3], and have become one hot research topic in mobile computing domains. In the recent years, there have been a number of published research papers addressing LBS. However, most papers primarily focus on the following areas:

- LBS infrastructure, framework, and architecture [4][5][6][7];

- Privacy preserving for LBS [8][9][10];

- Positioning techniques for LBS [11][12];

- LBS databases [13][14].

Till now, there are few publications discussing mobile LBS testing. There is a lack of systematic and effective test models and methods for test engineers to address LBS testing. The engineers often ask mainly the following questions about LBS testing.

1) How to select and test a set of locations for LBS?

2) How to test different types of location objects?

3) How to test millions instances of location objects and their information?

4) How to test moving objects with dynamical moving paths and patterns?

This paper focuses on cost-effective mobile LBS testing issues. The major contributions of this paper include four areas: 1) discussing the basic concepts, scope and challenges of mobile LBS testing; 2) proposing a novel test model for mobile LBS testing; 3) some coverage metrics are defined for evaluating quality of mobile LBS testing; and 4) providing case studies to show the effectiveness of the proposed test model.

The rest of the paper is structured as follows. Section Ⅱ discusses basic concepts and main challenges of LBS testing. Section Ⅲ presents a novel test model and a test approach for location-based mobile information services. Section IV reports the results of a case study. Section Ⅴ reviews and discusses published papers and related research work. Finally, concluding remarks and future research directions are given in Section Ⅵ.

II. Understanding Mobile LBS Testing

A. What is Mobile LBS Testing?

Location-based services are information, entertainment, services that are conveniently accessible by mobile users through GPS-enabled portable devices and mobile networks (e.g., 2G/3G/4G cellular telephone and Wi-Fi networks). Some organizations and scholars have defined LBS, and the classic definition is presented below.

Definition 1: LBSs are information services accessible with mobile devices through the mobile network and utilizing the ability to make use of the location of the mobile device [15].

Based on our recent literature survey, there is a lack of published papers on LBS testing for mobile apps, and also no detail definition of mobile LBS testing. Here we define it as below.

Definition 2: Mobile LBS testing refers to testing activities for native and Web apps on mobile devices to ensure quality in location-based functions, behaviors, information, and quality of service.

B. The classifications of mobile LBS

In recent years, mobile LBS have become more and more popular, and many mobile LBS apps are developed in various domains, such as navigation, information, emergency, advertising, tracking, games, management, and leisure. According to behavior characteristics of LBS, mobile LBS are divided into three classifications: basic location services, location context information services, and location context interactive services. Those services have different characters and features, and are compared in Table I.

TABLE I.   MOBILE LBS SERVICES CHARACTERS

	Basic location services	**Location context information Services**	**Location context interactive services**
Objects	Mobile user	Location objects	Mobile objects
Positions	Moving along paths	Fixed positions	Moving along different paths
Typical Services	Map services, Location services, Navigation services	Search services, Access services, Update services	Interactive services
Service mode	Push way	Push way, Pull way	Push way Pull way
Real-time feature	High	Low	High
Infor-mation	Digital map information	Location context information	Mobile Object properties
Domain	Map Navigation Emergency	Information Advertising tracking Managements Leisure	Game, social network, intelligent automobile

Basic location services - The mobile apps provide basic digital maps, location, and navigation services to help mobile users find correct ways to their destination. Some early map and navigation apps provide basic location services for mobile users.

Location context *information services -* The mobile users search nearby location objects and then access or update information of location objects. Those location objects have fixed positions, and provide static or dynamic information. Mobile users access information with push or pull ways. Most of information services are not real time service. The location context information services are widely used in many domains, for example, bossiness, advertising, management, and leisure.

Location context *interactive services -* The multiple mobile objects interact with each other in same location contexts. Those mobile objects may be mobile users, mobile servers, or other objects with position. Location context interactive services provide different behaviors or functions according to locations or location relations between different objects. Most of location context interactive services are real-time services, and are applied in some new domains, such as game and intelligent automobile.

Today, there are hundreds of mobile apps with location-based information services, such as, Yelp, Booking, *etc*. So this paper focuses on testing location-based mobile information services.

C. Why is mobile LBS Testing Important?

Mobile LBS have been identified as killer services of mobile apps, which provide many conveniences and interests for mobile users. However, few published papers address the importance of mobile LBS testing. Here, its primary reasons and importance is listed as follows.

Reason #1: Multiple techniques for LBS - Mobile LBS normally use many different techniques, such as mobile computing, geographic information systems, GPS, cloud computing, Internet, *etc*. Those techniques make mobile LBS testing more complex.

Reason #2: Location impact for LBS - Location is the most critical factor for mobile LBS, which affects information, behaviors, functions and QoS, such as performance, dependability, privacy, *etc*.

Reason #3: Higher costs of LBS testing - Due to numerous locations, different kinds of location objects with changing information, and moving objects with unpredictable paths, the test engineers have to spend a lot of time and effort on mobile LBS testing.

D. Test activities and goals

Mobile LBS testing tends to focus on the following activities and goals:

LBS Functionality and behavior testing - activities that validate location-based service functions, such as map and navigation services, information services, interactive services, *etc*.

LBS information and data testing - activities that validate LBS information and data, such as, positions, information, moving paths of mobile object.

LBS QoS testing - activities that evaluate system load, performance, reliability, availability, scalability, and throughput in different location contexts;

LBS security and privacy testing - activities that check user data security and location information privacy.

LBS compatibility and connectivity testing - activities that assess mobile browser and platform compatibility, especially compatibility with different location techniques, and diverse wireless network connectivity.

LBS regression testing - Mobile LBS are updated frequently for fixing faults, adapting to new devices and platform versions, and enhancing functions. Regression testing is continuous for mobile LBS.

E. Scope of mobile LBS testing

LBS testing focus on testing and validating location related functions and features of mobile apps. As shown in Fig. 1, the scope of LBS testing includes the following six types of testing activities.
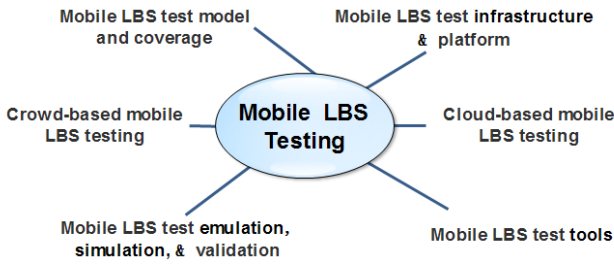

Figure 1. The Scope of Mobile LBS Testing

LBS test model and coverage - This refers to the activities that analyze and model main factors of mobile LBS, such as locations, location objects, location-related function and behavior, *etc*. The test models are used to generate test cases, and to analyze test coverage.

LBS test infrastructure and platform - This refers to the study of solutions on how to build the infrastructure and platform supporting automatic mobile LBS testing.

Crowd-based mobile LBS testing - This refers to the crowd-based test approach for mobile LBS, which allows to test mobile LBS in more extensive ranges.

Cloud-based mobile LBS testing - This refers to the cloud-based test approach for mobile LBS, which provides dynamic test resources and location simulation for mobile LBS testing.

LBS test emulation, simulation, and validation - This refers to study and apply different mobile LBS testing approaches.

Mobile LBS test tools - This refers to develop test tools to support automatic testing of mobile LBS.

III. THE TEST MODEL AND COVERAGE

This section presents a novel test model for location-based mobile information services. Based on this test model, a test approach and some coverage metrics are proposed.

A. The Mobile LBS Test Model

1) Basic concepts and definitions

First, some basic concepts about location contexts are defined. These concepts are important to design test cases for mobile LBS.

Definition 3: A location $l_i = (long_i, lat_i)$ is a pair of real numbers representing the longitude $long_i$ and the latitude lat_i of the location on the Earth surface.

Definition 4: The range $range_i(l_i, r_i)$ denotes one circular range, the center of the circular range is l_i, and the radius of the circular range is r_j.

Definition 5: A path $path_i(l_{i1}, l_{i2}, \cdots, l_{ik})$ denotes a moving path through a set of location points $(l_1, l_2, \cdots, l_k)$.

2) Test object model

The mobile LBS test object model is proposed to represent the core objects and their relations. This model is used to design test cases and help test coverage analysis for mobile LBS. As shown in Figure 2, mobile LBS have four types of core objects: location context, Map, location objects and services.
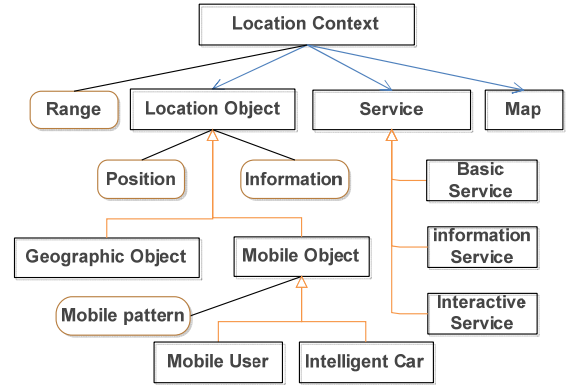

Figure 2. Mobile LBS test metal-model

The location context LC for location-based mobile services is denoted as a 4-tulpe

$$LC(Range, Map, LocationObjects, Services).$$

Location context defines the range of mobile LBS, which includes a set of location objects, a set of services and relations between objects and services.

Map is used to display position of location objects and mobile users. Map also has some behavior, such as zooming, moving, *etc*.

Location Objects are a set of objects with positions. There are two types of location objects: geographic objects and mobile objects. Geographic objects have fixed positions, and mobile objects have different moving patterns. Location objects can provide static or dynamic information.

Services are a set of services in a location context. The main location context services include basic location services, information services and interactive services. Those location context services may have various behaviors in various location contexts.

B. The Test Coverage for LBS

In order to analyze and ensure test quality, some test coverage metrics are defined to evaluate mobile LBS testing.

Definition 6: The range test coverage Cov_{reg} is defined as the ratio of the sum of all tested ranges Rng_t to the all ranges Rng_a. It is formulated as below.

$$Cov_{reg} = \frac{Rng_t}{Rng_a} \qquad (2)$$

In Figure 3, a mobile LBS app is used in whole USA, and is fully tested in 17 states. Then the range coverage is about 50%.
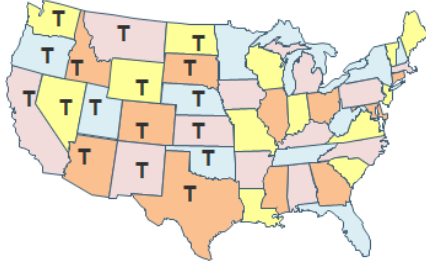

Figure 3.   Example of range coverage

In most situations, only a few ranges are tested because of restricted test resources. Then how to select and prioritize test locations and ranges is a serious issue for mobile LBS testing.

Definition 7: The location object type test coverage Cov_{LOt} is defined as the ratio of the number of tested location object types Num_{TLOt} to the number of all location object types Num_{ALOt}. It is formulated as below.

$$Cov_{LOt} = \frac{Num_{TLOt}}{Num_{ALOt}} \qquad (3)$$

Location object type test coverage is used to ensure that all type of location objects should be tested at least once.

Definition 8: The location object test coverage Cov_{LOi} is defined as the ratio of the number of tested location objects Num_{TLOi} to the number of all location objects Num_{ALOi}. It is formulated as below.

$$Cov_{LOi} = \frac{Num_{TLOi}}{Num_{ALOi}} \qquad (4)$$

Location object test coverage is used to test and evaluate information and behaviors of all location objects. However, there may be thousands of location objects in the location context, and then we have to select a small part of location objects to test.

Definition 9: The services test coverage Cov_{Srv} is defined as the ratio of the number of tested services Num_{TSrv} to the number of all services Num_{ASrv}. It is formulated as below.

$$Cov_{Srv} = \frac{Num_{TSrv}}{Num_{ASrv}} \qquad (5)$$

Definition 10: The object services test coverage Cov_{OSrv} is defined as the ratio of the number of tested services for every type location object Num_{TOSrv} to the number of all services for every type location object Num_{AOSrv}. It is formulated as below.

$$Cov_{OSrv} = \frac{Num_{TOSrv}}{Num_{AOSrv}} \qquad (6)$$

The same services may concern different types of location objects, and then we need test services for every type of location object individually.

C. Model-driven Test approach for Mobile LBS

The model-driven approach that we use for mobile LBS testing consists of five steps. The first step is to model location objects, location context Services for under-test mobile LBS using the proposed meta-model. The second step is to select some test locations according to mobile user contexts. The third step is to design test cases according to the test models of mobile LBS. The fourth step is to analyze test coverage of mobile LBS. The last step is to execute test cases and analyze test results. This process is shown in Figure 4.
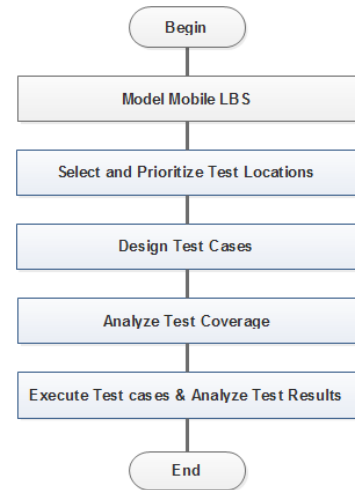

Figure 4.   Model-driven test process for mobile LBS

The main difficulty for mobile LBS testing is to select and prioritize test locations and location objects. Simulation-based and emulation-based test approaches are cost-effective to test

different location contexts and location objects for mobile LBS. However, field test is necessary for mobile LBS. Then crowd-based testing is a novel and convenient approach to test a large number of location contexts and location objects for mobile LBS.

IV. CASE STUDY

To demonstrate the proposed approach for mobile LBS testing, we applied the approach to test one selected mobile app Tripadvisor. We conducted this case study in detail as described below.

A. The Test Model for Tripadvisor

Tripadvisor provides location-based travel services, which helps travelers to search and book hotels, flights, restaurants based on their locations. The test model for Tripadvisor is presented in Figure 5.
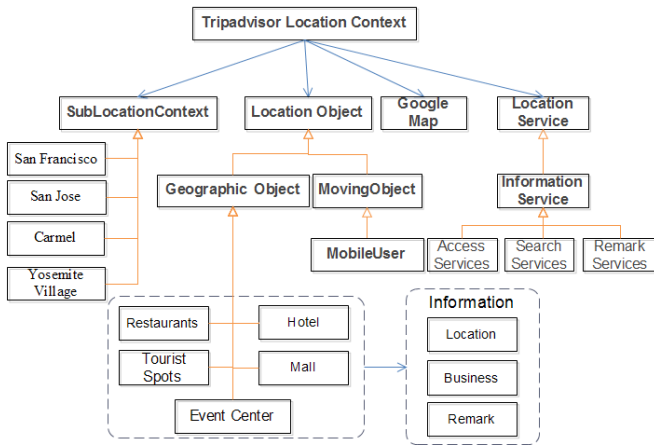

Figure 5. Test Object Model for Tripadvisor

TABLE II. TRIPADVISOR LBS DESCRIPTIONS

LBS		Description
Location context Services	Search Services	Search nearby location objects, such as: hotels, restaurants, tourist spots, malls, and event centers.
	Access Services	Access information of nearby location objects, such as positions, phone numbers, business hours, and remarks.
	Remark Services	Mobile users remark some nearby location objects by their experiences.

Tripadvisor provides some location objects, including restaurants, hotels, tourist spots, malls, and event centers. Those location objects have positions, remarks, and business information. Tripadvisor provides some services for mobile users to search, access, and remark location objects. Those services are described in Table II.

B. Test approach for Tripadvisor

1) Selecting and specifying test locations

For testing LBS, we must select and specify test positions and ranges firstly. Through Tripadvisor is being used in many countries and cities, we only test Tripadvisor in San Francisco Bay Area because of restricted test resources. Four different

locations are selected, which represent different kinds of location contexts. The details about selected test locations are described in Table III.

TABLE III. TEST POSITIONS FOR TRIPADVISOR

No	Location	Position	Description
LC1	San Francisco City	37.805623 -122.406719	In big city
LC2	San Jose City	37.808517, -122.411934	In medium-sized city
LC3	Carmel	36.554986 -121.922041	In small city
LC4	Yosemite Village	37.742004, -119.582939	In tourist area

2) Designing test cases for Tripadvisor

Based on location contexts, test cases (TC) are designed for mobile LBS testing. All types of location objects and location context services should be tested at least once. We designed 58 test cases for Tripadvisor LBS in 4 location contexts based on the proposed test model. The test cases and tested location objects are shown in Fig 6, and test coverage is analyzed in Table IV.
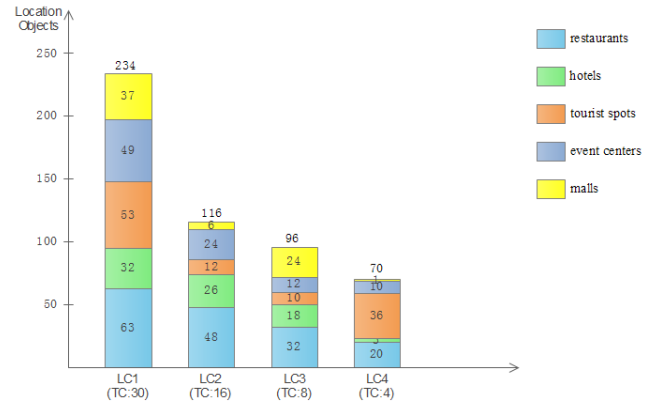

Figure 6. Tripadvisor test cases and tested location objects

The five type location objects have been tested, and three location context services have also been tested. We only selected and test four location contexts, and it is too small to calculate range test coverage. There are millions of location objects in Tripadvisor, we test 516 location objects from 8763 located objects in the four selected location contexts. Then we calculate location object test coverage in the four selected location contexts. Finally, 4 faults were found.

TABLE IV. TRIPADVISOR LBS TEST COVERAGE

Test Cases	Cov_{LOt}	Cov_{LOi}	Cov_{Srv}	Cov_{OSrv}	Faults
58	5/5	516/8763	3/3	15/15	4

Using our proposed approach, the test engineers design test cases for testing more location objects and services based on the test model. According to table IV, all location objects and

services are tested fully. The approach helps to reach high test coverage, to improve test effectiveness and save test costs.

V. RELATED WORK

Nowadays, mobile LBS have become one hot research topic in mobile computing domain, and many papers have been published to address different areas in mobile LBS.

Some mobile LBS frameworks and architectures have been proposed. Chengcheng Dai proposes a LBS framework using vehicular ad-hoc networks [4]. R. Gobi proposes a communication framework for data management in LBS [5]. A conceptual framework for personalized location-based tourism apps leveraging semantic web to enhance tourism experience is proposed by Mahmood [6]. Rui Jose proposes the AROUND architecture for supporting location-based services in the Internet environment [7].

The privacy issues are serious for LBS. Ben Niu proposes two dummy-based solutions to achieve k-anonymity for privacy-area aware users in LBSs with considering that side information may be exploited by adversaries [8]. K. G. Shin presents a comprehensive overview of the existing schemes for protecting LBS users' privacy [9]. An adaptive location privacy-preserving the system is presented, which allows a user to control the level of privacy disclosure with different quality of location-based service [10].

Position technique is the key for LBS. HuangChi Chen proposes a novel indoor positioning technique based on neural network [11]. Al Nabhan presents a new strategy in achieving highly reliable and accurate position solutions fulfilling the requirements of Location-Based Services (LBS) pedestrians' applications [12].

However, there are a few of publications about mobile LBS testing. Jerry Gao discusses the issues and difficulties of mobile LBS testing [16]. Ke Zhai proposes a suite of metrics for prioritizing test cases for regression testing of LBS [17]. Huichun Chu proposes a two-tier test approach for location-aware mobile learning systems [18]. Solveig Bjørnestad presents an example study about evaluation of a location-based mobile news reader [19]. Jiang Yu analyzes test requirements, and presents a scalable testing framework for mobile LBS [20]. However, those papers do not discuss test model for mobile LBS.

We have proposed an initial test model for function services of mobile LBS [21]. In this paper, we improve and perfect the test model by considering location context, range, moving pattern and path, and some new test metrics are defined for evaluating mobile LBS test coverage.

VI. CONCLUSION AND FUTURE WORK

Recently, mobile LBS have become popular among research groups. Because mobile LBS provide context-sensitive functions based on location information, this brings many new difficulties and challenges for mobile LBS testing.

This paper analyzes the main factors about mobile LBS testing. A new test object model has been proposed, and some test metrics are defined to evaluate test coverage for mobile LBS. The test object model and test metrics help test engineers

to design test cases for mobile LBS, and to improve test quality by higher test coverage.

Future research directions include four areas: a) selecting and prioritizing positions and ranges for mobile LBS testing; 2) enhancing the test approach to validate and verify correctness and timeliness of location-based services; 3) designing and specifying moving paths for mobile objects; and 4) developing automatic test tool supporting mobile LBS testing with emulation and simulation.

REFERENCES

[1] Adrian Holzera, and Jan Ondrusb. "Mobile application market: A developer's perspective", Telematics and Informatics, 2014, 28(1): pp.22-31.

[2] Sergio Ilarri, Arantza Illarramendi, Eduardo Mena, Amit Sheth, "Semantics in Location-Based Services," IEEE Internet Computing, vol. 15(6), 2011, pp.10-14.

[3] Shang-Pin Ma, Wen-Tin Lee, and Chia-Hsu Kuo, "Location Explorer with information services: A mobile application to deliver location-based web services", 2013 IEEE International Symposium on Next-Generation Electronics (ISNE 2013), pp.283 - 286

[4] Chengcheng Dai, Chiyin Chow, and Jiadong Zhang. "Utilizing road-side infrastructure for location-based services in vehicular ad-hoc networks", the 8th International ICST Conference on Communications and Networking, 2013, pp.546-551.

[5] R. Gobi, Dr. E. Kirubakaran, and Dr. E. George Dharma Prakash Raj. "ComFrame: A Communication Framework for Data Management in Mobile Location Based Services", International Journal of Computer Science and Telecommunications, vol.3(7), 2012, pp.65-68.

[6] Mahmood, F.M., Bin Abdul Salam, Z.A. "A conceptual framework for personalized location-based Services (LBS) tourism mobile application leveraging semantic web to enhance tourism experience", the 3rd IEEE International Conference on Advance Computing (IACC), 2013, pp.287 - 291

[7] Mohammad AL Nabhan, Suleiman Almasri, Vanja Garaj, Wamadeva Balachandran, and Ziad Hunaiti, "Client-Server Based LBS Architecture: A Novel Positioning Module for Improved Positioning Performance", International Journal of Handheld Computing Research, vol.1(3), 2010, pp.1-18

[8] Ben Niu, Zhengyan Zhang, Xiaoqing Li, and Hui Li "Privacy-area aware dummy generation algorithms for Location-Based Services ", 2014 IEEE International Conference on Communications (ICC), 2014 pp.957 - 962

[9] K. G. Shin, X. Ju, Z. Chen, and X. Hu, "Privacy protection for users of location-based services," IEEE Wireless Communications, vol.19(1), 2012, pp. 30-39.

[10] Zhu, I., K.-H. Kim, and P. Mohapatra. "An Adaptive Privacy-Preserving Scheme for Location Tracking of a Mobile User." in IEEE Internation Conference on Sensing, Communication, and Networking. New Orleans, USA, 2013, no pp. 9.

[11] Chen HuangChi, Chen YuJu, Chen ChihYung, Wang Shuming T., Yang JenPin, Hwang ReyChue, "A New Indoor Positioning Technique Based on Neural Network", Advanced Science Letters, Vol.19(5), July 2013, pp. 2029-2033

[12] AL Nabhan, Mohammad Mousa, "Adaptive, reliable, and accurate positioning model for location-based services", Brunel University School of Engineering and Design PhD Theses, 2009

[13] Suprio Ray, Rolando Blanco, Anil K. Goel, "Enhanced database support for location-based services", Proceedings of the 4th ACM SIGSPATIAL International Workshop on GeoStreaming, 2013, p.22-25.

[14] Ray S., Blanco R., Goel, A.K., "Supporting Location-based Services in a Main-Memory Database", 15th IEEE International Conference on Mobile Data Management, 2014, pp.14-18

[15] Virrantaus, K., Markkula, J., Garmash, A., Terziyan, V., Veijalainen, J., Katanosov, A., Tirri, H., "Developing GIS-supported location-based services," Proceedings of the Second International Conference on Web Information Systems Engineering, 2001, vol.2, pp.66-75

[16] Jerry Gao, X. Bai, W. T. Tsai, and T. Uehara, "Mobile application testing: a tutorial", IEEE Computer, vol.47 (2), 2014, pp.26-35

[17] Ke Zhai, Bo Jiang, Chan, W.K., "Prioritizing Test Cases for Regression Testing of Location-Based Services: Metrics, Techniques, and Case Study," IEEE Transactions on Services Computing, 2014, vol.7, no.1, pp.54-67

[18] Hui-Chun Chua, Gwo-Jen Hwangb, Chin-Chung Tsaib, Judy C.R. Tsengc, "A two-tier test approach to developing location-aware mobile learning systems for natural science courses", Computers & Education, vol.55(4), 2010, pp.1618−1627

[19] Bjornestad, S., Tessem, B., Nyre, L., "Design and Evaluation of a Location-Based Mobile News Reader," 4th IFIP International Conference on New Technologies, Mobility and Security (NTMS), 2011, pp.7-10

[20] Yu J, Tappenden A, Miller J et al., "A scalable testing framework for location-based services," journal of computer science and technology, vol.22(2),2009,386-44

[21] Oum-EI-Kheir Aktouf, Tao Zhang, Jerry Gao, Tadahiro Uehara, "Testing location-based function services for mobile applications", The First International Workshop on Mobile Cloud TaaS (MCTaaS 2015), 2015, in press.