Mobile Data Management in Indoor Spaces

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***Abstract*—This advanced seminar presents the fundamental mobile data management concepts behind the realization of innovative indoor information services that deal with all aspects of handling indoor data as a valuable resource, including data modeling, data acquisition, query processing, privacy and energy consumption. The goal is to provide an overview of the emerging field of indoor data management with a particular emphasis on mobile systems. We tackle the topic from a wide range of perspectives: fundamentals, definitions, current state, academic & industrial perspective, reality & visionary scenarios as well as future challenges. The seminar captures the big picture, such that interested researchers and practitioners can expand their study by following the references. Our presentation will be carried out through the lens of an experimental Indoor Information System we developed at the University of Cyprus, coined Anyplace, which has obtained three international awards and was ranked the second most accurate indoor localization technology by Microsoft Research at IEEE/ACM IPSN'14.**

Keywords*—*Indoor, Mobile, Privacy, Crowdsourcing, Big Data

I. Introduction

People spend 80-90% of their time in indoor spaces[1] such as offices, undergrounds, shopping malls and airports. The omni-present availability of sensor-rich mobiles has boosted the interest for a variety of indoor location-based services, such as, in-building guidance and navigation, inventory management, marketing and elderly support through Ambient and Assisted Living [9], [25].

The indoor localization literature is very broad and diverse as it exploits several technologies, including: *Infrared, Bluetooth, visual or acoustic analysis, RFID, Inertial Measurement Units, Ultra-Wide-Band, Sensor Networks, Wireless LANs, etc.*; including their combinations into hybrid systems. Most of these technologies deliver a high level of positioning accuracy, comparable to GNSS that does not operate indoors, however they require the deployment and calibration of expensive equipment, such as custom transmitters, antennas or beacons, which are dedicated to positioning. This is time consuming and implies high installation costs.

To enable the uptake of indoor applications in an energy-efficient manner and without expensive additional hardware, modern smartphones rely on a new generation of *Indoor Positioning Services (IPS)*, which provide the accurate location (position) without additional infrastructure but only exploit hardware readily available on the mobile terminal-level or the network level. Examples of such services include *Skyhook, Google, Navizon, Infsoft, Indoo.rs, Ubee.in, IndoorAtlas* and our in-house *Anyplace* [28] system[2]. Developing IPS efficiently, creates a new spectrum of information management challenges ranging from crowdsourcing indoor models and radiomaps, big-data processing of radio signals, localization algorithms, privacy, encoding schemes and others.

This advanced seminar presents the fundamental mobile data management concepts behind the realization of innovative indoor information services that deal with all aspects of handling indoor data as a valuable resource, including data modeling, data acquisition, query processing, privacy and energy consumption. The goal is to provide an overview of the emerging field of indoor data management [14], with a particular emphasis on WiFi-based mobile systems. We will provide a taxonomy and accompanying Venn diagram to illustrate the indoor positioning services landscape. IPS can be classified based on whether they require additional infrastructure or not, whether location is calculated on the terminal or network side, and whether the system employs localization data contributed by professionals or by individuals that generate *Volunteered Geographic Information (VGI)* that inherently contains error.

We will tackle the topic from a wide range of perspectives: fundamentals, definitions, current state, academic & industrial perspective, reality & visionary scenarios as well as future challenges. The seminar captures the big picture, such that interested researchers and practitioners can expand their study by following the references. Our presentation is carried out through the lens of an experimental Indoor Information System we developed at the University of Cyprus, coined Anyplace, which has obtained three international awards and was ranked the second most accurate indoor localization technology by Microsoft Research at the 13th ACM/IEEE Conference on Information Processing in Sensor Networks (IPSN'14), Berlin, Germany [27]. To our knowledge, this is the first advanced seminar covering explicitly this combination and it follows directly from our recent work in [7], [15], [16], [18], [19], [23], [27], [28].

In the first part of the seminar, we will provide an extensive coverage of indoor localization technologies and relevant systems. We provide a thorough explanation of the field through an extensive taxonomy that captures the intrinsic characteristics of emerging systems built for smartphone devices. The given presentation should allow the audience to grasp basic and advanced concepts ranging from Geolocation databases, WiFi

[1] US Environmental Protection Agency, http://epa.gov/iaq/

[2] Anyplace Indoor Information Service, http://anyplace.cs.ucy.ac.cy/

fingerprint-based systems as well as hybrid combinations. In the second part of the seminar, we will particularly focus on mobile data management concepts for modeling indoor spaces, distance measures, query processing and analytics as well as markup languages, modeling systems and tools. We will also focus on privacy issues that arise, given that location tracking in indoor space can occur at a very fine granularity, thus it can reveal the stores and products of interest in a mall we've visited, doctors we saw at a hospital, book shelves of interest in a library, artifacts observed in a museum and generally anything else that might publicize our preferences, beliefs and habits. We will conclude the seminar with the presentation of the challenges and opportunities in the field ranging from big data processing challenges (e.g., handling WiFi fingerprints) [19], device-diversity management [18], prefetching and forecasting of user's motion in indoor spaces [16].

II. Description of Target Audience

The goal of this advanced seminar is to convey a basic and advanced understanding of the unique characteristics, challenges and opportunities of indoor data management and how these can facilitate Mobile Data Management research, evaluation and applications. The advanced seminar is targeted to scientists with a basic understanding of mobile data management, but no knowledge of indoor data management technologies is required. In particular, this seminar addresses the following audience:

- Graduate and Undergraduate Students
- Mobile Data Management Researchers/Educators
- Industry Developers

This seminar covers, but is not limited to, the following MDM 2015 topics of interest:

- Context-aware computing and location-based services
- Indexing and query processing for moving objects
- Location and mobility semantics
- Location tracking of vehicles and moving objects
- Mobile cloud computing
- Mobile crowd sourcing
- OS and middleware for mobile and pervasive computing
- Security and privacy issues for ubiquitous systems
- Pervasive data management and incentive models
- Adaptive location-dependent query processing and optimization
- Human-centric activity management
- User interfaces and usability issues form mobile applications

Outline

In this section we outline the tentative structure of the advanced seminar during the conference. The final layout of the seminar will be reflected in its powerpoint presentation available through the seminar website[3].

A. Introduction to Indoor Mobile Data Management

- Definitions and Motivation
- Applications and Incentives

B. Indoor Localization Systems Taxonomy

- Infrastructure-based vs. Infrastructure-free
- Terminal-based vs. Network-based
- Participatory vs. Opportunistic
- Privacy vs. No Privacy
- Overview of Systems: Mazemap.com, Epsilon [24], ALPS [20], SmartCampusAAU [11], Ekahau.com, KAILOS [10], Active Campus [5], Place Lab [17], Redpin [6] Zee [29], FreeLoc [31], Molé [21], Anyplace [28]

C. Indoor Location

- Global Navigation Satellite Systems (GNSS): GPS, Galileo, GLONASS, IRNASS, Beidou-2
- Inertial Measurement Units (IMU): 3D acceleration, 3D gyroscope, digital compass using Pedestrian Dead Reckoning (PDR)
- Smartphone APIs: GPS, Cell_ID DBs, WiFi_ID DBs (Skyhook, Google Geolocation API, Wigle.net DB+API, Mozilla Location Service API)
- WiFi Fingerprinting (RadioMaps): RSSI, Localization (KNN, KNN, WKNN), map matching, location fusion, magnetic mapping
- Hybrid and Future Directions: WiFi+IMU [18], WiFi+Bluetooth [3], UWB, LiFi, magnetic-based (IndoorAtlas), 2G+3G+4G+WiFi+magentic (GloPos).

D. Modeling, Query Processing and Analytics

- Symbolic modeling [4], [13] and Modeling Tools [12]
- Distance Measures [26]
- Query Processing: Spatial [32] and Top-K [30]
- Analytics: Dense Locations [2] and Hotspots [1]
- Markup Languages (IndoorGML [22] and Systems (IndoorOSM [8])

E. Privacy and Crowdsourcing

- Definitions (Location Privacy)
- Temporal Vector Map Algorithm [15]
- Crowdsourcing Radiomaps: Incentives, Quality and Effort [7], [28]

[3]Seminar slides: http://dmsl.cs.ucy.ac.cy/tutorials/mdm15/

F. Conclusions and Future Directions

- Challenges and Opportunities: Big Data [19], Device Diversity [18], Radiomap Prefetching [16]
- Future Vision

Biographies of Advanced Seminar Presenters

Christos Laoudias got his Ph.D. in Computer Engineering from the University of Cyprus in 2014. He got his Engineering Diploma in Computer Engineering and Informatics and his M.Sc. in Integrated Hardware and Software Systems from the University of Patras, Greece in 2003 and 2005, respectively. Christos joined the Department of Electrical and Computer Engineering, University of Cyprus in 2006 as a research associate working on location-aware applications and positioning platforms under EU-funded projects. Later he joined the KIOS Research Center for Intelligent Systems and Networks at the University of Cyprus working in the field of indoor/outdoor localization as a graduate researcher (2008-2014) and a postdoctoral researcher. Recently, he joined Huawei Technologies Design Center in Dublin, Ireland as a geolocation algorithm expert to guide an outdoor GPS-less positioning project.

He has been involved in the development and demonstrated several award-winning prototype systems for indoor localization, tracking, and navigation. These include a best demo award at the 13th IEEE International Conference on Mobile Data Management in 2012, a 1st place award in the EVARILOS project Indoor Localization Open Challenge in 2014, and a 2nd place award in the Microsoft Indoor Localization Competition (Infrastructure-free approaches) at the 13th ACM/IEEE International Conference on Information Processing in Sensor Networks in 2014.

He is a member of the IEEE Communications Society and serves as TPC member of the International Conference on Indoor Positioning and Indoor Navigation. His research interests include wireless networks, mobile communications and data management, positioning and tracking technologies, location-based services (LBS) and fault tolerant location estimation.

For more information please visit: http://goo.gl/dQIU4c

Demetrios Zeinalipour-Yazti is an Assistant Professor of Computer Science at the University of Cyprus, directing the Data Management Systems Laboratory (DMSL). He got his Ph.D. and M.Sc. in Computer Science and Engineering from the University of California - Riverside in 2005 and 2003, respectively. He got his B.Sc. in Computer Science from the University of Cyprus in 2000. He has also been a visiting researcher at the Network Intelligence Lab of Akamai Technologies Cambridge, USA in 2004. His research interests include Data Management in Systems and Networks, particularly: Mobile and Sensor Data Management, Big Data Management in Parallel and Distributed Architectures, Spatio-Temporal Data Management, Network and Web 2.0 Data Management, Crowd and Indoor Data Management as well as Data Privacy Management.

He has served as the PC Co-Chair of IEEE MDM'10, VLDB's DMSN'10 and ACM MobiDE'09, the General Chair for ACM MobiDE'10, the Contest Chair of IEEE ICDM'10, the Organization Chair of HDMS'10, the Demo Co-Chair for IEEE MDM'13 and the Panel Co-Chair for IEEE MDM'14. Currently, he serves as the Workshops Co-Chair for IEEE MDM'15 and also co-organizer for the HuMoComP'15 workshop at IEEE MDM'15. He has also been a referee for several IEEE and ACM journals, including TKDE, TPDS, TIST, TMC, TEC, TVT, TC and VLDB Journal.

He has participated in projects funded by the US NSF #0220148, #0330481, EU's CoreGRID Network of Excellence (#IST-2002-004265), EU's EGEE (#IST-2003-508833) and by the Cyprus RPF. He has participated in EU's Marie Curie Host Fellowships for the Transfer of Knowledge "SEARCHiN: SEARCHing in a Networked world", EU's CONET Network of Excellence (#FP7-224053). He is the PI of projects "SmartNet: A Hardware Testbed for Testing Smartphone Network Applications", funded by UCY and has also been the PI of project "SenseView: An Energy Efficient Data Acquisition Framework for Wireless Sensor Networks", funded by the Open University of Cyprus.

He has finally extensively been involved in industrial Research and Development projects: Cywee (Taiwan), Microsoft/Nokia/Aalto (Finland), Geomatics and MTN (Cyprus) but has also technically also lead several experimental mobile data management services including: i) Anyplace (an Indoor Information Service); ii) SmartLab (a programmable smartphone testbed); and iii) Rayzit (a crowd messaging network). He is a member of the ACM (Sigmod), the IEEE (Computer Society) and the USENIX Association.

For more information please visit: http://goo.gl/Xxs0vE or the DMSL website: http://dmsl.cs.ucy.ac.cy/.

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