Controlling Accuracy/Privacy Trade-offs in Indoor Location Systems

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Abstract: Mobile services such as navigation apps are essential tools of our daily life. For a conscientious user, the best way to ensure one's privacy protection is to stop using connected devices. To prevent opting for such extreme solutions, we advocate to use tools that *leverage* both the privacy and the utility aspects in mobile computing, to meet user-defined objectives. Using control theory, this thesis will be focused on designing a novel mechanism specific to *indoor* location systems, able to protect privacy while guaranteeing high location accuracy.

Keywords: Privacy, mobile computing, indoor location, control theory

Host laboratory

Spirals (Self-adaptation for distributed services and large software systems) is a project-team at Inria Lille – Nord Europe research center. Its research program focuses on defining self-adaptive distributed software services and systems. In particular, it targets two key properties that are self-optimization (continuous monitoring and decision making to improve systems) and self-protection (automation of security and privacy protection). These objectives are applied to two target environments: mobile computing and cloud computing; and a variety of adaptation tools are used such as control theory.

Context

Indoor location challenge The use of mobile devices has become predominant in our private and professional lives. Most mobile applications require user location data to deliver their service (*e.g.* navigation, fitness, games) or to improve it (*e.g.* social medias, weather forecast, meeting apps). The focus of the thesis is on *indoor location systems*, in public places (train stations, malls) or for private actors (warehouses, worksites). In contrast with the general outdoor context, indoor systems

show challenges and specificities, both in the technical aspect (increased need for precision, multi-modal sensing, bounded set of 3d positions, available map knowledge) and in the usage perspective (new services, collaborative users, short visits) [4].

Accuracy vs. Privacy Indoor Location Systems face major open research questions regarding accuracy and privacy [1]. On the one hand, location accuracy still needs to be improved and backed with a solid, multi-platform evaluation methodology [6]. On the other hand, the increased utility of the service brought by location data is at the cost of users' personal data sharing, leading to privacy threats. Those threats include users re-identification, retrieval of their points of interests, social relationships and future mobility prediction [7]. Protection mechanisms from general location-privacy literature have to be reinvented to address indoor challenges [3]. Most of all, there is an inherent trade-off between location accuracy and privacy protection. For instance, a protection mechanism leveraging privacy by adding noise to the location data reduces location precision, *i.e.* service accuracy.

Need for adaptation The time-perspective plays a central role in location-aware systems. Time variations have 4 main origins. First, the location accuracy varies spatially, depending on the quality of the sensing infrastructure, and thus through time, as users are mobile in their environment. Second, human mobility is broadly repetitive, a user next movement is fairly predicted using past location data and a mobility pattern model [5]. Third, the privacy level of users is dependent on the locations risk associated with their semantics (health, worship, etc.), or other spatiotemporal properties (i.e. the presence of a crowd to hide in). Eventually, the users' desired trade-off between service accuracy and privacy protection vary, e.g. in urgent/sensitive situations.

Research questions The emerging research questions are i) how to measure and leverage indoor location accuracy? ii) how to measure and enforce privacy protection? iii) how to achieve a trade-off between accuracy and privacy? iv) how to dynamically ensure the accuracy/privacy trade-off despite runtime variations?

Approach

Self-adaptation using control theory To achieve accuracy/privacy trade-off *at runtime* we advocate to rely on self-adaptation. Several research methods can be used to realize self-adaptation, such as queuing theory, machine learning, or control theory [8]. The advantage of control theory relies on the explainability and guarantees it can provide on the behavior of the controlled system. Additionally, the control-based formulation naturally emphasizes the time dynamic perspective, and allows to have guarantees during time transient phases.

Control formulation In the control-based approach, location-based services will be considered as black-boxes, i.e. elements processing input signals and generating output ones [2]. Outputs are the measure of the current state of objectives such as accuracy, privacy or computational speed; and inputs are knobs to leverage those states, such as location sensors selection/combination or data noising. The system has thus multi-inputs and multi-outputs. The control approach consist in designing a controller that will generate *at runtime* the adequate knobs values in order for the measures to meet the objective trade-off, despite environment variations.

Objective The research objective is to study the design and implementation of a control mechanism specific to indoor location systems able to protect privacy while guaranteeing high location accuracy. The novelty regarding the state-of-the-art are three-fold: i) time variations awareness, ii) tunable trade-off, and iii) tackles multi-modal location sensing.

Workplan

The 3-year thesis project will be organized and timed as such:

- **Literature review (6M)** Familiarization with the state-of-the-art on multi-modal location sensing, indoor location precision, location privacy, control of accuracy/privacy trade-offs.
- **Metrics definition (6M)** Analysis of the usages and threats of indoor location systems, and identification and characterization of privacy and utility metrics.
- **Identification of knobs (10M)** Accuracy and privacy knobs will be investigated. Their impact on metrics will be quantified and modeled. Experiments will be carried out using an indoor mobility dataset and a location collection tool provided by the team[1][2].
- **Accuracy/privacy trade-off control (10M)** A controller will be developed tackling the properties of the system: multi-input multi-output, subject to environmental disturbances, possibly non-linear, and with switches between services.
- **Manuscript redaction (4M)** Dissemination of the thesis work—additionally to publications—will be ensured through the writing of a manuscript.

The PhD candidate will publish and present the obtained results in top conferences and journals.

Required skills

The candidate is required to have a master or equivalent diploma in one of the following areas: control of dynamical systems, mobile computing. An interest for the topic of privacy is a plus. Good English skills, both for speaking and writing, are required.

Application

Please apply by e-mail to Sophie Cerf by the **22th of April, 2022**. Attach a resume, Master transcripts and coordinates for 1-2 persons that can recommend you.

[1] `https://apisense.io/`
[2] `https://www.indoorlocation.io/`

References

[1] Anahid Basiri et al. "Indoor location based services challenges, requirements and usability of current solutions." In: *Computer Science Review* 24 (2017), pp. 1–12. ISSN: 1574-0137. DOI: https://doi.org/10.1016/j.cosrev.2017.03.002. URL: https://www.sciencedirect.com/science/article/pii/S1574013716301782.

[2] Sophie Cerf et al. "A Control-Theoretic Approach for Location Privacy in Mobile Applications." In: *CCTA 2018 - 2nd IEEE Conference on Control Technology and Applications*. 2nd IEEE Conference on Control Technology and Applications (CCTA 2018). Copenhague, Denmark, Aug. 2018, pp. 1488–1493. DOI: 10.1109/CCTA.2018.8511409. URL: https://hal.archives-ouvertes.fr/hal-01863625.

[3] Sylvia Holcer et al. "Privacy in indoor positioning systems: a systematic review." In: *2020 international conference on localization and GNSS (ICL-GNSS)*. IEEE. 2020, pp. 1–6.

[4] Haosheng Huang et al. "Location based services: ongoing evolution and research agenda." In: *Journal of Location Based Services* 12.2 (2018), pp. 63–93.

[5] Eduardo Mucelli Rezende Oliveira et al. "On the regularity of human mobility." In: *Pervasive and Mobile Computing* 33 (2016), pp. 73–90.

[6] Francesco Potortì et al. "Evaluation of indoor localisation systems: Comments on the ISO/IEC 18305 standard." In: *2018 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*. IEEE. 2018, pp. 1–7.

[7] Vincent Primault et al. "The Long Road to Computational Location Privacy: A Survey." In: *Communications Surveys and Tutorials, IEEE Communications Society* (2018), p. 1. DOI: 10.1109/COMST.2018.2873950. URL: https://hal.archives-ouvertes.fr/hal-01890014.

[8] Eric Rutten, Nicolas Marchand, and Daniel Simon. "Feedback control as MAPE-K loop in autonomic computing." In: *Software Engineering for Self-Adaptive Systems III. Assurances*. Springer, 2017, pp. 349–373.