

Techniques for countering privacy threats of Location-based services

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Most of the social networking services today exploit location-based data in one way or another. Services like Facebook allow users to GeoTag their current location and tag themselves and their friends. In exchange the service can use the data to offer recommendations, news and so on. While the users of the services are often aware that they are providing personal locational data, its pervasiveness and accuracy may come as a surprise and have serious repercussions when it comes to users' real-life privacy. A malicious actor such as a burglar could exploit the data a user provides to for example find out their street address and times when they are not home. This seminar paper reviews and evaluates several techniques used to preserve and protect users' privacy when using Location-based services. The goal for the techniques is to counter several threats Location-based Services face in such manner that users can still use said services without compromising their security.

1 Introduction

Location-Based Services (LBS) are applications that operate on geographical or other location based data. Original LBSs can be traced back to mid-20th century, but what is understood by LBS today is tied to the mid-21st century emergence of G3 networks and hand-held devices with GPS capability [1]. Many contemporary LBSs take a form as a part of a social networking applications such as Facebook, Foursquare and Instagram. There are several ways LBSs work. They can make use of users' mobile device's GPS and provide services based on users' whereabouts when requested or continually monitor users' location [6]. Some services allow users to *check-in* to pre-determined venues or points of interest (POI) whereas other allow more exact location with the GPS data. This practice is commonly known as *GeoTagging*.

LBSs do not come without security risks. By publishing their location on the internet exposes users to threats in the real world. A malicious agent, for example a burglar, could monitor one user's LBS usage and e.g. determine when the user is not at their residence. Using that information the attacker could orchestrate a break-in without the risk of being caught red-handed [2]. While many applications require user to explicitly publish their locational data, users also often do it unknowingly. For example many contemporary smart phones as well as digital cameras automatically embed metadata to photographs and it can contain privacy sensitive information such as coordinates and the time the photograph was taken [2]. In some cases the user themselves does not expose their location data explicitly, but with certain LBSs supporting *User Tagging*, a user's acquaintance can expose the user without them having a say for it. Thus a user can be associated with places, people and other information they would rather keep private.

The obvious privacy issues have been researched a lot and many techniques have been presented which address one or more possible privacy threats LBSs face [6]. These range from offering users options to rule how, where and when can their locational and identity data used to more technical solutions such as query enlargements and encryption-based techniques. Each of them have have their uses and shortcomings: They can only address a certain set of privacy threats and may come with pre-assumptions and computational costs.

In this paper we first review threats LBSs face in section 2. Then in section 3 we take a look at the techniques designed to address different kinds of privacy threats in LBSs. Section 4 compares and evaluates the techniques in respect of their intended use as well as other techniques. Section 5 will be the concluding part summarising the state of privacy in Location-Based Services and also shortly addressing the future trends of the field.

2 Threats in Location-based Services

A privacy threats in LBS can be defined as events during which an adversary can gain information about the user which they consider sensitive[6]. Threats fall into two major categories: Release of sensitive location information and re-identification through location information. In the first case, the identity of the user is known but the location information associated with that identity is considered sensitive and somehow made available for the adversary. In the latter case the user would like to have their identity kept secret but the adversary can exploit their location data to narrow down their possible identities in the set of other associated identities thus reducing their degree of anonymity. [6] list four different privacy threat vectors and [3] add one more. The vectors are location privacy, absence privacy, co-location privacy, identity privacy and correlation privacy.

2.1 Location Privacy

Location privacy is the most straightforward of attack vectors. Whenever a user publishes their location they associate their identity with that location and possibly reveal information they consider sensitive. Even though a user can generalise their location it is not guaranteed to be safe. For example, a user would GeoTag themselves in a LBS whilst visiting a bar with a friend, but instead of using the exact location they would use the more general location like the part of town as the tag. Now if the aforementioned friend would happen to meet another friend at the bar too and GeoTag them both but now using the exact location of the bar, an adversary with the access of both GeoTags could easily deduct first user's exact location as well as the fact that they are accompanied by the third friend, both being pieces of information the first user did not explicitly wish to expose [6].

2.2 Absence Privacy

Absence Privacy can be regarded as the other side of the location privacy. As the user publishes information about where they are at the given moment, they simultaneously expose explicitly where they are not. This threat factor also has a temporal dimension. For example, an adversary planning a break-in to a user's home can use the user's location information to estimate how long they will approximately be absent in order to avoid being caught while on the crime scene.

2.3 Co-location Privacy

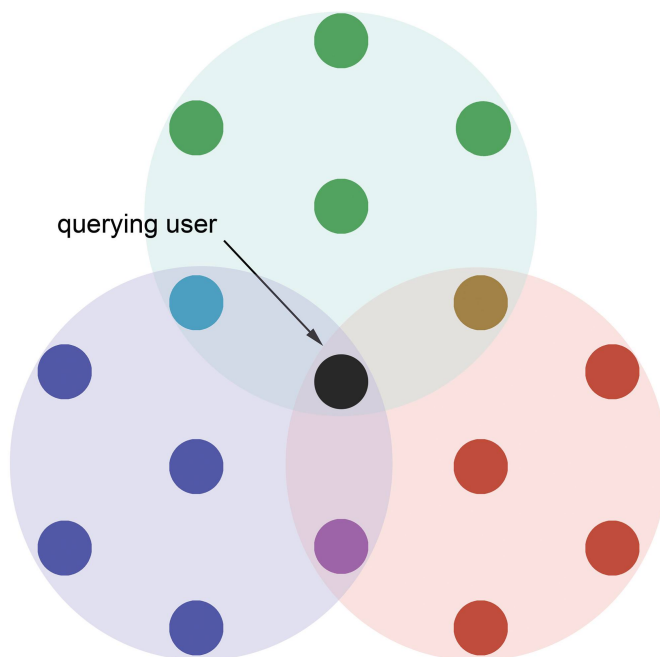
Co-location Privacy refers to a privacy threat in which the adversary monitors multiple users' location information in order to associate other users with each other and different locations. For example, if user A GeoTags themselves and their friend user B to a location and simultaneously user C tags themselves and their friend user D at the same place, an adversary with the access to the information of only A and C can possibly violate the privacy of both B and D as being associated with someone on the other party at the given place can be considered sensitive by users.

2.4 Identity Privacy

Identity Privacy refers to a scenario in which a user employs an obfuscated identity such as a pseudonym to protect their real identity but their identity can be revealed by associating them with a certain location. For example, the user is a 30-year-old male who is using a location-based dating service at his workplace. In the service he uses a pseudonym because he considers the fact that he is using the service to be embarrassing and thus sensitive. Now if he happened to be the only male of 30 years at his workplace and his supervisor would happen to check out the dating service and only search for users in their immediate vicinity, the supervisor would find out that the 30-year-old user is using the service during work hours effectively violating the user's privacy. In a scenario like this the pseudonym does naught to protect the users real identity.

2.5 Correlation Privacy

Correlation Privacy is sort of a special case when it comes to the nature of the privacy threat vectors. Correlation attack is possible when using query enlargement techniques such as k-anonymity [5]. For instance, consider a user using a LBS which takes advantage of the user's mobile device's satellite positioning capabilities and requires user to send their location information to the service periodically. To protect user's identity, the LBS employs k-anonymity by sending user's data among with many other users' in the vicinity so that the user cannot be singled out of the data set. However, the anonymisation is done case-by-case. As a result of this, if the user would send the data consecutively and an adversary would be able to access these queries, the user would be included in every data set and could be easily identified with a simple interjection of the data sets. Figure 1 illustrates, how multiple queries may possible identify the user present in all data sets.



Credit: *Kiia Pitkänen, used with permission*

Figure 1: A user present in all data sets can be easily singled out with a simple interjection.

3 Techniques for countering the privacy threats

As there are possible privacy threats in LBS so is there techniques designed to address and mitigate their severity. [4] classify different threat countering techniques into four classes.

- **Query enlargement techniques** take the user's location and generalize it thus increasing the user's degree of anonymity.
- **Dummy-based techniques** generate fake locations and send them along with the user's actual location effectively hiding their whereabouts among the dummies.
- **Progressive retrieval techniques** retrieve candidate query results iteratively from the server so that the user's exact location will not be revealed.
- **Transformation-based techniques** use cryptography to hide users' data, but provides users deciphering keys to decrypt the data they need.

3.1 Query Enlargement techniques

Query enlargement techniques rely on the notion, that when sending location data to the server, if included is other identities from the given location, the user sending the data can not be easily identified from among other identities. The idea was first formulated by Latanya Sweeney[5] and in her paper it is applied to traditional databases. We assume that the database is made of rows of entries which consist of columns of attributes. The purpose of k -anonymity is to have a database with at least k occurrences of a certain attribute. When someone queries the database with these attributes they will get at least k entries which correspond to the given query, but the query can not be used to find a specific row. In this manner the data of a single user is safe but the dataset as a whole can still be used meaningfully for statistical study. To achieve a database which satisfies k -anonymity, one must first identify the so-called *Quasi-identifiers* which are usually non-unique attributes in the data set but can be used together with other quasi-identifiers to form unique identifiers. To make sure that the Quasi-identifiers cannot be used to identify single entries, they either have to be *suppressed*, made less

distinguishable by replacing the value or part of it with a wild card notation, or *generalised* so that multiple values fall to a certain broader category.

4 Evaluation of the techniques

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