Reliable, User-Contributed GSM Cell-Tower Positioning Using Context-Aware Photos

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ABSTRACT

Data regarding the physical location of GSM cell towers is important for many practical applications. Unfortunately, such data is not freely available in many countries. We present a system where users who tag and organize their camera-phone photos on Flickr implicitly contribute information about the physical location of cell towers. The system has been deployed on a test basis for 3 months, and currently has about 100 active users. In this period, users mapped a total of 1799 cell towers to a city level or zip (postal) code level. At this rate, assuming uniform distribution of users and cell towers, 10,000 users could map every GSM cell tower in the United States in less than 10 weeks.

Categories and Subject Descriptors

H.4.M [**Information Systems Applications**]: Miscellaneous

General Terms

Human Factors, Algorithms

Keywords

Cell positioning, cell tower, context-aware, camera phone, photos

1. INTRODUCTION

Many ubiquitous computing applications using cellular networks stand to benefit from a reliable mapping of cell tower IDs onto real-world locations. Examples of such applications include local-search applications, location-sharing and disclosure systems [4], and tools for media organization. Regretfully, adequate cell tower location information is not widely available. Previous attempts to create cell tower location datasets have relied upon costly "war driving" [3], or specialized methods such as games [1]. Neither method is likely to enjoy mass distribution.

We present a system that ties cell tower positioning to camera-phone-based personal photo collections. Incentives that are natural to photo collections (such as sharing, tagging and organizing) can bring users to contribute information about cell tower locations, even when unaware of the beneficial side effects of their actions.

Our system includes a camera-phone capture application, ZoneTag [5], and a web-based component through which users contribute information. On the phone, ZoneTag records contextual information for each photo, including the IDs of cell towers detected by the phone around the image capture time. When uploading the photo to the ZoneTag server, if data about the given cell towers already exists in the ZoneTag database, the system will associate the image with that the derived location. If the cell towers are not known at the time of image upload, users can specify the photo's (and therefore with the given cell tower's) location using a web interface (Figure 1). The location can be specified in zip code (American postal code) or city granularity.

As many users understand the benefits of location-based information for searching and browsing images, they frequently add location information to their photos. Our system leverages the actions of this motivated subset of users for the benefit of all users in the system. The system uses social information tied to individual users and photos to manage known problems with user-contributed data (such issues include labeling mistakes and spam) as well as to handle issues that arise from the "fuzziness" of cell signal propagation and coverage (e.g., cell overlap).

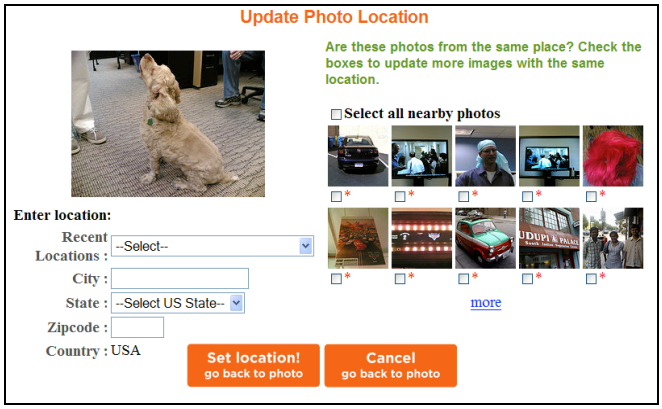

Figure 1. The Location input page where users can tell ZoneTag about the location of a photograph. Nearby photos (from the same cell tower) can be updated as well.

2. SYSTEM OVERVIEW

In this section, we first describe the method in which cell tower metadata is associated with images by the ZoneTag mobile photo client. Then, we illustrate two states of the application – when the tower's location is unknown (or incorrect), and when the tower data already exists in our database.

The ZoneTag mobile client provides context-aware upload of camera-phone photos to Flickr [6]. When the user chooses to upload a newly captured image, the ZoneTag client sends the image data to the ZoneTag server. Along with the IDs of any cell tower the phone is currently connected to, as well as a list of towers seen in the previous five minutes ("cell history").

ZoneTag adds a link to the Flickr photo page that allows the user to input the location of each image, and other images taken at the

same cell tower. Thus, if the ZoneTag server does not have information about the cell tower location, the user can supply this data when viewing the image on Flickr. The user can enter the zip code, or the city and state where the photos were taken. When the user inputs this data, the system associates the location data with all cell towers connected with the image, together with the ID of the user who entered this data.

ZoneTag looks up a cell tower to location mapping (e.g. Tower A) in the following order:

a. Previous mapping of Tower *A* by the user who took the image.
b. Mapping of Tower *A* by users that are connected to the user on Flickr (in Flickr's social network).
c. Mapping of Tower *A* by any ZoneTag user.

If Tower *A* has not been mapped by anyone, the server considers other towers from the image's cell history in similar fashion. If the cell history search fails, the server uses cell adjacency data (constructed from other uploaded images) to find other neighboring cell towers, whose location may be known.

This prioritized lookup scheme makes the system robust in the face of various issues that arise in this domain. First, user-contributed data is prone to mistakes as well as malicious spam. Trusting the user and the user's social network data first can potentially filter some of these issues. Second, cell tower coverage is "fuzzy". For example, coverage from Tower *A* can overlap with other towers; it can also transcend zip code or city boundaries. On one hand, this fuzziness means the system can never be perfect: two users can take two photos in two different cities while their phones are connected to the same cell tower. If cell tower location alone is used, one of the photos is guaranteed to be associated with wrong location data. However, the personal-social approach can provide more accurate results, by prioritizing locations that individual users, and their contacts, have frequented in the past. Future enhancements could incorporate cell triangulation, or loops [2], for improved accuracy, as well as more advanced models of data verification and trust.

3. DEPLOYMENT

ZoneTag is currently deployed to about 100 active users in the United States. These users have taken more than 10066 images using the system. For the deployment, we seeded the system with data from a number of sources, including prior cell-spotting data and cell tower data supplied by members of the ZoneTag development team. This initial seeding allowed us to give some users (especially in the San Francisco Bay Area) a good "out-of-the-box" experience.

Note that the ZoneTag phone client can connect the phone via Bluetooth to a GPS device. ZoneTag can then capture both the cell information and the GPS information associated with each photo, removing the need for user input of the given cell tower's location. The use of GPS devices was not common amongst our users; results reported here do not include user data that was received by this technique. This data is included in our "seed" set.

In the period since ZoneTag was deployed, 44 users have updated the location of at least one photograph. In all, our users have contributed zip code information for 349 cell towers with an additional 135 cell towers being given city level information. When combined with the cell adjacency data (from images' cell history information) we find our users have provided city level location information for 1,799 distinct cell towers. This total represents 2% of the estimated 90,000 US GSM cell towers. At this rate, and assuming uniform distribution of cell towers and users, 10,000 users could map every GSM tower in the United States in less than 10 weeks.

Using a combination of seed and user-contributed data, a total of over 6331 uploaded photos (62.9%) were associated with location information at the time of upload. Our users manually added location information to over 819 images, bringing the total number of location-tagged images to almost 7,150 (71% of all photos uploaded). We have observed a strong correlation between user activity levels and willingness to update a photo's location. Users who add location data to their photos take an average of three times as many photographs as users who never added location data. The breakdown of number of contributions per user follows a power law, as expected. Finally, there is also a correlation between the total number of images taken in a location and the probability that a user will contribute the location information. We found that the 71% of the location-tagged images were taken in just 59% of the total cell towers seen by the system, suggesting that "active cells", in which more photos are taken, are more likely to be learned by the system.

4. Conclusions

Reliable GSM tower-positioning database can be built given user-contributed data about images. Such a system provides value not only to users who actively add location data to photos, but also to passive users who only consume automatically generated added location data. The data collected by the system can also be used for other ubiquitous computing applications that would benefit from city-and zip code granularity of location data.

We believe that rates of data entry by users can be improved by streamlining the user interface where location information is entered, and by supporting data entry on the mobile client. In addition, we are currently investigating how different incentive schemes can accelerate the rate of user contributions.

The cell tower database we developed could be made available via a web-based API. For details, please contact the authors.

5. REFERENCES

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