Bluetooth Pooling to Enrich Co-Presence Information

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ABSTRACT

Bluetooth has become a widely used source of co-presence information to determine a user's social context. However using Bluetooth in this way has several technological limitations including sensing time and effective range. This paper describes the technique of "Bluetooth pooling" which aggregates Bluetooth metadata collected from multiple users and propagates it among proximal users to create a more accurate record of co-presence. We also present the results of applying the Bluetooth pooling technique to a real world dataset of cameraphone photos annotated with Bluetooth co-presence metadata collected from over 65 users over 7 months.

Keywords

Bluetooth, aggregation, social context, mobile media metadata, cameraphone, location-based services

INTRODUCTION

Bluetooth is an RF-based networking technology allowing short range wireless communication between devices. Its dual properties of short range (typically < 30 feet) and unique identifier (MAC address) allow Bluetooth enabled devices to be "aware" of other active Bluetooth devices nearby. This awareness has been leveraged by several researchers [1, 2, 3] and developers [6] to provide information about a user's social context and to enable communication between proximal peers.

While Bluetooth is an excellent source of co-presence information, it is not without drawbacks. The power consumption of the Bluetooth radio often limits the mobile device to polling for surrounding devices rather than continuous operation. The polling process is slow (taking up to 1 minute) and the device cannot connect to other devices while polling. The coverage of the sensing is also reduced (the device may miss some active devices) as the number of active devices in the vicinity increases. Since Bluetooth devices are usually small personal mobile devices, they are also affected by antenna orientation and interference from surrounding metallic objects.

We have developed a method of aggregating the Bluetooth presence information collected from multiple users and propagating it among proximal peers to create a more complete record of co-presence—we call this method "Bluetooth pooling". We have applied Bluetooth pooling to a dataset collected through the University of California at Berkeley School of Information Management and Systems Garage Cinema Research's "Mobile Media Metadata 2" (MMM2) project [2] that leverages contextual metadata and photo sharing histories to suggest likely sharing recipients for a user's cameraphone photos. With Bluetooth pooling among collocated devices we have seen a 40% increase in the coverage of Bluetooth co-presence metadata vs. Bluetooth metadata gathered only by single devices.

MMM2 PROTOTYPE

We deployed the MMM2 cameraphone metadata collection and photo sharing software with 66 Nokia 7610 cameraphone users over 7 months at the University of California at Berkeley. The MMM2 phone client application recorded a "snapshot" of the context in which the photograph was taken. The collected metadata included the cameraphone user ID, the active GSM cell tower, surrounding Bluetooth device IDs, network time, and GPS coordinates. This metadata was then uploaded to the MMM2 server and the MMM2 photo sharing application used the Bluetooth proximity information and user photo sharing history to offer users a ranked list of "suggested recipients" with whom the user might wish to share the cameraphone photo.

Since the system was deployed to a reasonably homogenous group of participants—including 40 students from a single class—there were several occasions where multiple users took photos at the same place and time. While such a concentration of Bluetooth-enabled cameraphone users may not be currently very common in the United States, we believe that the increasing market share of Bluetooth-enabled cameraphones and other devices will lead in the near future to such Bluetooth user densities as are currently seen in some parts of Europe and Asia. Although we did collect a large amount of additional contextual metadata, for the purposes of this paper we focus on boosting the collection and coverage of Bluetooth co-presence metadata.

BLUETOOTH POOLING

Bluetooth pooling is a two step process: 1) establish co-presence of two users; and 2) propagate any missing Bluetooth co-presence metadata between those users.

Establishing Co-Presence

Since the MMM2 system provides us with snapshots of the Bluetooth devices present when a photograph is taken rather than a continuous history, we decided to use an ag-

gregation technique for sparse time series data similar to [4]. In Bluetooth pooling, co-presence is established using the Bluetooth devices sensed in common between two different photographs' metadata. We use a simple moving window to examine the collected Bluetooth co-presence metadata. If we come across two or more photographs in the same window that have at least one sensed Bluetooth device in common, we assume that those two photos were taken within physical proximity of one another.

The co-present photos may have been taken by the same user, different users, or some combination thereof—this allows us to find commonalities among photos taken by the same user as well as different users. Empirical testing on our dataset has shown that a 4 minute window enables us to establish co-presence among most sensed Bluetooth devices while not adding sensed Bluetooth devices that have in fact left the vicinity.

Metadata Propagation

Once the co-presence of a series of photographs has been established, we check to see if there are any sensed Bluetooth devices that do not appear in all of the co-present photos' metadata. If such Bluetooth devices are found, we then add the metadata about the missing Bluetooth devices (Bluetooth MAC address and alias) to co-present photos that do not possess it. We also ensure that: 1) the metadata is only transferred once; and 2) that photos can only acquire metadata from photos that contain directly sensed information about a co-present Bluetooth device.

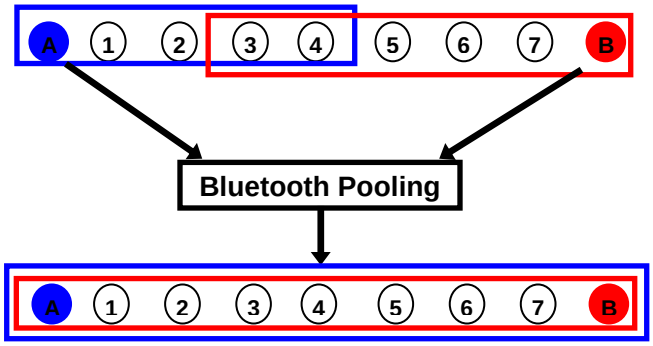

Figure 1: Bluetooth Pooling Scenario

Scenario

An illustration of how Bluetooth pooling works is shown in Figure 1. Imagine if User A and User B are at the same location along with 7 other active Bluetooth devices. User A takes a photo and senses Bluetooth devices 1 through 4. User B then takes a photo a few minutes later and senses Bluetooth devices 3 through 7. If we perform Bluetooth pooling, we will find that devices 3 and 4 are in common between User A's and User B's metadata for photos that were taken just two minutes apart. In this way we can infer that User A and User B overlapped in physical place and time without them actually having to sense each other directly. Bluetooth pooling will then combine their sensed Bluetooth devices and say that User A and User B each sensed Bluetooth devices 1 through 7 and each other while taking their respective photographs.

CURRENT AND FUTURE WORK

Of the over 14,000 photos in the MMM2 dataset, we have applied Bluetooth pooling to the 7352 photos that have directly sensed co-present Bluetooth device metadata. Since Bluetooth pooling requires metadata from multiple users we performed it on the server rather than on a mobile client. However, it would be possible to run the same process using Bluetooth networking techniques described in [5]. Additionally we performed our testing as a batch process, but it can easily be modified to run in real time.

Using a pooling window of 4 minutes we added additional co-present Bluetooth device metadata to 677 photos (9.2% of the photos). The photos boosted by Bluetooth pooling showed on average a 40% increase in the number of co-present Bluetooth devices—from 5.88 sensed co-present Bluetooth devices per photo to 8.25. In all we propagated a total of 1603 Bluetooth devices among the photos and increased the total number of instances of sensed Bluetooth devices from 20,881 to 22,484 (increase of 7.67%).

Our future work includes generating a ground truth for this dataset by querying our users about which Bluetooth devices were actually present when and where their photos were taken and applying the Bluetooth pooling technique to propagate other types of metadata such as GPS coordinates, user applied location tags, or indoor/outdoor image classification among collocated users. The privacy implications of this research also require further investigation.

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