Social Linking and Physical Proximity in a Mobile Location-based Service

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ABSTRACT

In this paper we collected and examined the indoor location traces of users of an indoor location-based social network service called Find & Connect deployed at an academic conference, to explore the relation between users' physical proximity and the connecting properties of their social links. We define a parameter called encounter to represent the physical proximity between users, and also select two kinds of social links that exist in the online social graph formed during the conference, i.e., friendship and sharing common friends. Using these parameters, we present a correlation study of encounter duration, frequency and distribution with the formation and strength of the social links. Results show that, on average, an increasing encounter duration between users leads to a high possibility of the establishments of social links, while afterwards this increment of encounter duration slows down after establishments of social links. We also find users that are highly sociable (with regards to the number of friends and common friends) indicate a higher proximity interaction with their friends, and similarity of a pair of users suggests more and longer encounters between them. This means, for two kinds of social links we select, there is a strong relation between social linking and physical proximity.

Author Keywords

Mobile location-based services, online social network, social computing, physical proximity, ephemeral social network.

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces – Evaluation/methodology, H.5.3 [Information Interfaces and Presentation]: Group and Organizational Interfaces – Computer supported cooperative work.

General Terms

Design, Human Factors, Experimentation, Measurement.

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INTRODUCTION

Social media links people together into a social network through the shared things or objects. In social media, the shared objects are virtual resources like photos or physical resources such as job postings. Much of these social networks are maintained online and are therefore called online social networks. In these online social networks, social linking is accomplished through friend requests where a person sends a request to another person to add that person as a friend, a following request where the person can just follow the activities of the other without the other person's consent, or comments to another person's post. However, in real life, we make friends with others usually by meeting someone face-to-face and having a verbal conversation with them. These interactions are presently not captured automatically in online social networks, and do not have support for them.

In addition, many people are now accustomed to receiving "friend spam"[18], where they receive many friend requests from people whom they do not know. In this online age, user popularity is measured by how many "friends" that they have [17], but we have this problem as to how many of your online friends are really your friends. Therefore, we have this serious disconnect between physical and online social networks.

As a result, physical proximity can play a significant role in social networking such as making new friends, because it helps you recognize how you know that person based on where and when you met [12]. If we can build a system that captures these physical proximity interactions and integrate them within the event where the system is deployed, then we believe that this will improve the quality of social linking, reduce social link spam, and create meaningful social relationships among users at an event.

In this paper, we address the following problem: Can physical proximity within a shared physical environment influence social linking and social relationships among users?

We define social linking as friendship and following (people that you follow) and we define the physical proximity by the encounter that two users are close to one another, which is indicated by the encounter distance between two users and the encounter duration. We build a system called Find & Connect that records physical proximity encounters in a physical environment and allows participants to make friends through friend requests based on participants that are physically at the environment, and also follow their status updates. Find & Connect provides a system to integrate the online and physical communication together based on Wi-Fi indoor positioning and facilitates users to create social networks from ephemeral encounters and activities.

We conducted a field trial of Find & Connect at the Ubiquitous and Intelligent Computing (UIC 2010) conference [19]. To analyze the relationship between physical proximity and online social linking, two sources of data are used: (1) who has physical proximity with whom, and (2) the online relationship of these people and the social network character of each user. To understand the social linking behavior, we examine the friendship link in Find & Connect used at the conference and compare that with the encounters. We then create social networks based on encounters and friendship links and use them to determine if encounters (physical proximity) can influence social linking (becoming friends). We find that the physical proximity network is much tighter than the online friend network [7]. Specifically, we use the following criteria for our evaluation of the influence of encounters on social linking and vice versa:

1) Before the formation of online social links (friendship), the changes of encounter duration along time.

2) Encounter duration and number vs. friend network (after friend formation) based on the different users classified by the number of friends they have.

3) Encounter duration distribution vs. friend network (after friend formation) based on the different users classified by the number of friends they have.

4) We also present additional studies, such as the results for a pair of users that are not directly connected but do have a friend in common.

Our results show that (1) a larger value of encounter duration will suggest a higher possibility that these two users will add each other as a friend or they will share a common friend, and (2) after two users become friends or share a common friend, the increment ratio of encounter duration between them decreases along time, yet, (3) the duration between a pair of friends is always bigger than those who only have common friends. Last, (4) participants that add more friends will have more encounters, longer encounter duration with each of their friends than those that have a smaller number of friends, but have a similar distribution of duration of each encounter, this also holds between a pair of users who only have common friends.

The results indicate that (1) physical proximity has a positive effect on online social links formation, and (2) more active online interaction like having more friends indicate a longer and more frequent proximity interaction in the physical world.

Our contributions are the following. First, we build a complete conference and location system based on physical proximity and location history for an indoor environment, and create social linking features to connect the users in real time. Second, we deploy this system at an actual conference and provide rich features that are integrated with the conference program using phones with a user interface which allowed participants to navigate their way at the conference, communicate with others, and upload comment activity to an online social networking site, which we believe we are the first to do so. Third, we quantify social linking, user behavior, and its relationship to physical proximity interactions for direct and indirect pairs of social links.

The rest of this paper is organized as follows. Related work is discussed in the next section, and then we present our methodology in our research in Section 3. The system, experimental setup and social features of Find & Connect are given in Section 4, along with the description of the datasets. In Section 5, we present the quantitative results of our experiments of the correlation between physical proximity and online social linking for direct friend pairs and indirect common friend pairs. Finally, we conclude the paper in Section 6, followed by a discussion of potential applications as well as future work.

RELATED WORK

There has been some theoretical and empirical work on how a user's action or behavior can be correlated to his/her social networks. By examining the membership in an online social network, Backstrom et al [3] discovered that there is correlation between the action of a user joining an online community and the number of friends who are already members of that community. Marlow et al [13] exhibited a correlation between social connectivity and tag vocabulary by considering the tag usage problem in Flickr and studied the set of tags placed by a user and those placed by the friends of the user. Different from the above two, Singla et al [16] used the characteristics of each user in the social network, rather than one or several particular behaviors of users to analyze the relation between communication and personal behavior. They used the demographic data, like a person's age, gender and geographical location, and personal interest of MSN Messenger users as well as the communication or chat records to form the social network graph of users, and showed that there is a strong relation between the social linking on the instant messaging network and the category of users' characteristics. In the above work, the user behaviors they examined are only conducted online, or inferred by their online profiles or records. Therefore, all the results and conclusions are only applicable when we only take users' online links and interactions into account, and when it comes to those links established in the physical world and those interactions committed offline, the lack of quantitative data for presenting users' offline behaviors make it hard to infer and bridge the relation between online social linking and offline personal behaviors.

Due to the ubiquity of mobile device usage and mobile network coverage, a great number of location-based applications and services have extended the range of users' behavior from just online to both online and offline. For example, some services detected and collected proximity encounters by radio frequency identification technology (RFID) [11] or Bluetooth such as Aka-Aki [1], are used to recommend friends based on the frequency of proximity. Some applications such as Foursquare use location as a check-in mechanism to allow users to post, share their own locations and view locations of others based on these similarities to recommend relevant friendships. Others use proximity encounters to introduce people and infer a user's social network like Serendipity [3]. The extension of user behavior on these location-based online social services brings out a new research interest for social linking and user behaviors: whether there also exists a strong relation between online social linking and offline personal behavior, and if it does exist, is this relation different than previous obtained results and conclusions?

In order to analyze this correlation, measurement of physical proximity is required. Firstly, among various offline surrounding contexts, people's physical proximity used by researchers can be one representative social pattern of user behaviors. For example, Eagle et al [9] use the Geographical location data collected through the GPS module on users' mobile phones to calculate the co-locations of users at certain times in order to obtain the pattern of a user's offline location tracks.

To measure the relationship between geography and friendship, Backstrom et al [4] utilize self-reported address data from Facebook users to get their physical proximity, and collect users' friend network ties in Facebook. The authors find that in social selection, probability of people adding Facebook friends is roughly inversely proportional to their distance at medium to long-range scale, while less sensitive to the distance in shorter distance scale. Work in [10, 15] use Bluetooth technologies to define the relative physical closeness and use this closeness (encounter duration and frequency) as the inference of new friendship links. In these works, the chosen social links have already been established and claimed by users themselves on online social networks, but they do not study the social influence of established social links on physical proximity after the links are formed. For example, after two people add each other as friends, does their physical proximity interaction increase in the shared physical environment? Exploring this is helpful to find how online social linking affects user behaviors in the real world. Work in [8] studied users' co-location traces based on the diverse location measurements and proposed location entropy, and predicted the friendship of two users by analyzing their co-location traces, where they discovered a positive relationship between the entropy of the locations the user visits and the number of social ties that the user has in the network.

However, GPS positioning methods used in former researches have accurate limits (on the order of 50 meters error) [10], thus they cannot omit the noisy proximities when no interaction is happening. Therefore, outdoor co-location cannot always infer offline interaction as expected. Considering this, we build an indoor proximity-based system called Find & Connect and regard indoor physical proximity of a higher accuracy resolution obtained through a WiFi-based positioning system [5, 14] to explore the relation between social linking and proximity in an indoor physical environment.

APPROACH AND METHOD

For our research problem, we make several hypotheses. H1: Physical proximity between users in offline activities has a positive effect on the formation of online social links, that means if users have more and longer time of being proximate in physical environment, it is more possible they will be connected with each other online. H2: Establishments of online social links will increase the offline interaction between users, so that they will be more proximate or have longer proximity duration afterwards. H3: The more social the users are, like having more friends, the more offline interactions users will have, like having more and longer physical encounters with each friend on average, and this also applies to two users that are not friends but share common friends.

Motivated by the work of [8] where they discovered that users that are co-located according to their GPS location data together tend to have more online social interactions in Facebook, we want to examine whether these relations exist for indoor environments. We focus on indoor locations of users because to record any intense interaction especially indoor activities. Therefore, we seek a method to locate users' indoor position with WiFi positioning technology and then integrate this with an online social service that has similar social features with regular online social services like adding friends, getting updates of other users, and also provides some additional features to provide users with facilities to manage physical objects. The details of our system can be found from our previous work [7, 19].

To study the correlation of physical proximity and online social linking, we need to define some parameters to measure quantitatively the properties of both proximity and online social linking. First, for physical proximity, we can choose co-location where two people are in the same area or physically within a particular distance, or encounter where two people are co-located but they move close to each other before moving away. For representing offline interactions, we believe that encounter is a good parameter that takes into account human mobility and co-location, which happens during activities.

For social linking, similar to online social networks, we choose friendship as one of the online social links to study, because it is the most common and relevant means of social relationship between two users. According to some former works on user behaviors characterizing in online social networks [6], they show that users not only interact with 1-hop friends, but also have significant exposure to friends that are 2 or more hops away. In our paper, we choose those user pairs who are not friends but have at least one common friend (2 hops) in the online social graph because common friends help in expanding your social circle of friends.

After choosing these parameters, we perform a correlation analysis of those parameters to get some qualitative and quantitative results to examine our hypotheses for our research questions.

EXPERIMENTAL SETUP

To address our research problem, we build a system called Find & Connect that records physical proximity encounters in a physical environment and allows participants to make friends with participants at the environment. Find & Connect is a location and proximity-based mobile location-based service for physical events, which is based on the problem of how to use the resources in the physical environment to help facilitate social networking and vice versa. We conducted a field trial in the 7th International Conference on Ubiquitous Intelligence and Computing (UIC 2010) in October 2010. A total of 112 conference attendees downloaded and used Find & Connect during the trial. We first describe the system overview and the social features in Find & Connect, and then explain the dataset used from the trial.

System Overview

Find & Connect in the UIC 2010 conference provides a system to integrate the online and physical communication together based on Wi-Fi indoor positioning and facilitates users to create social networks from ephemeral encounters and activities. Aiming at bridging the gaps between users' offline interactions like physical proximity encounters or session attendance and their online social connections like friendship, Find & Connect has two integrated subsystems, an indoor location positioning system utilizing Wi-Fi to record locations of moving conference attendees, and a social network system providing an interface allowing users to build and extend their online social network and receive updates from their connections. The positioning client software installed in the user's mobile phone collects and uploads the Wi-Fi signal strength and MAC address of nearby Wi-Fi access points to the positioning server, which approximates the current position of the user through a learning and prediction process based on a previously established model of recorded Wi-Fi signal strengths in the indoor environment and newly received signal strengths from the clients. The Find & Connect web client on the user's mobile phone provides the user interface for accessing the conference and social networking features from the Find & Connect server. The Find & Connect server communicates with the positioning server to integrate the information of physical proximity interactions between users and provide location information of users. More details on the system architecture can be found in our previous work [20].

Social Features

To help users easily establish new social connections at a conference and find useful physical resources like session rooms during the event or social objects like interesting papers, several social features are created.

At its core, Find & Connect uses the conference resources as objects for social interaction and connection, in this case, the room, the session, and the paper. Attendees can *find* where the room and session is on the map and then *connect* with the people shown in the room on the map by viewing their profile, finding out what they have in common with them, and then deciding whether to become friends, to follow that person or to exchange contacts. Many mobile applications can perform the find feature such as [2], but few perform the connect feature. The novel part of Find & Connect lies in the integration of the social network with the conference program and the location. To integrate this social connection with the location, we allow attendees to view their encounters with others within close proximity. More on the encounters can be found in the next section. To enable social interaction using conference resources, attendees can add a paper as their favorites or share the paper with others, from which others can view the paper details and can decide to add the author to their social connections.

Dataset

Our dataset includes the proximity encounters between two attendees as computed by the Find & Connect server, their encounter distance and encounter duration. In addition, the dataset also includes all the friend pairs anonymized (hop = 1) and pairs of users who share common friends (hop = 2) obtained from the friend pairs. We do not consider user pairs that share a friend that is more than 2 hops because the social utility is low [6, 16] and our ultimate goal is to use the analysis to recommend friends based on encounters.

Encounter

Using the collected position data of users in Find & Connect, we define a parameter called *encounter* to denote physical proximity. We define an encounter if the distance between two people is within the *encounter distance threshold* and their distance lasts for at least the *encounter duration threshold* before they move away and are beyond the encounter distance threshold.

Let $U = \{u_1, u_2, ..., u_n\}$ be the set of unique user ids, and $e_{i,j}(t)$ be the encounter occurred between u_i and u_j at time t. Figure 1 illustrates an example of an encounter that

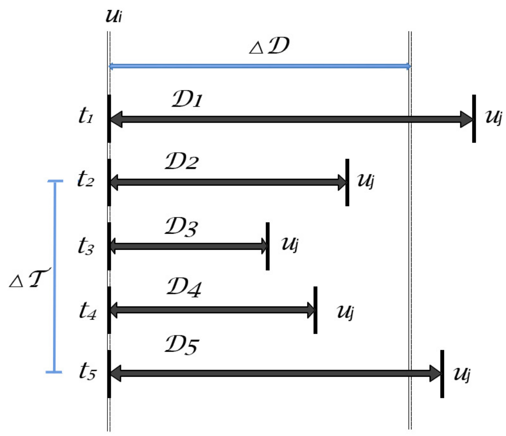

Figure 1. Defining an encounter between two users u_i and u_j.

occurs in our definition. ΔD is the defined encounter distance threshold, and t_1, t_2, t_3, t_4, t_5 are adjacent time points. At time t_1, the distance D_1 between users u_i and u_j is larger than ΔD, then at t_2 they move closer to a distance D_2 smaller than ΔD. We record t_2 as the start time of this encounter. Then they keep moving closer until t_5, where they move apart and their distance D_5 is larger than ΔD. We record t_5 as the end time of the encounter. Thus, we record the last distance less than ΔD between u_i and u_j at t_4 (distance D_4) as the encounter distance $D_{en}(e_{i,j})$, and $\Delta T(e_{i,j}(t_4)) = t_5 - t_2$ is the encounter duration.

In this paper, we concentrate on how and whether encounters can be used to help users to add these people as friends.

Friend Pairs (FPs) and Common Friend Pairs (CFPs)

The friend network is formed during the conference when people accept the friend requests, and the two people that are friends are called friend pairs (FP). Let $F = \{u_i\}$ be the set of user ids u_i who have at least one friend and if u_i and u_j are friends, then $F_i = \{u_j : u_j$ are all the friends of $u_i\}$ is the subset containing all the friends of u_i's. Let $FP_{i,j} = (u_i, u_j)$ denote the friend pair between users u_i and u_j, and $\{FP_{i,j}\}_{i,j \in F}$ be the set of all friend pairs in the friend network. For those users who are not friends but have one or more common friends, we call these pairs as common friend pairs (CFP). Let $CFP_{m,n}(u_m, u_n)$ denote another pair of users u_m and u_n that have at least one common friend, and $CFP = \{CFP_{m,n}\}_{m,n \in U}$ be the total set of all user pairs who share common friends.

We create social networks based on encounters and social linking interactions (friends and common friend pairs), and use them to determine if encounters (physical proximity) can influence social linking (becoming friend pairs and common friend pairs). From our earlier work [19], we showed that encounters can form opportunities for social linking in the context of making friends, however in this paper we explore in detail whether social activity of a user (i.e. her number of friends and her common friends) have an effect on encounters.

RESULTS

In this section, we present results from analyzing the dataset to examine our hypotheses on the correlation between social linking and physical proximity.

Direct Linking (FPs) and Encounters

We first address whether there exists a relationship between the physical proximity and the formation of friendship. From our trial, we want to see whether having greater encounter duration with a user will increase the possibility to add this user as a friend in the online social network. We also investigate how the encounter duration changes after two users become friends. To do this, we record the time when the friendship was established and use this time as the origin point (time 0) of the time axis with 30 minutes as the time interval. We discover 58 users in total who have at least one friend in the friend network and 220 FPs are generated, where each user has an average of 7.49 friends. For every pair who becomes friends, we calculate the cumulative duration of encounters that occur, with each encounter duration $\Delta T_{i,j}(FP_{i,j}, t)$ calculated at every time interval 8 hours before the friendship was established to 8 hours after the friendship was established. Then, suppose at time interval $t \in [t_a, t_b]$, we get the average cumulative encounter duration per pair

$$\overline{\Delta T} = [\sum_{i,j \in F} \int_{t_a \le t \le t_b} \Delta T_{i,j}(e_{i,j}(t))dt] / \sum_{i,j \in F} e_{i,j}$$

by summing the encounter duration of all FPs and dividing it by the total number of FPs. Figure 2 shows the cumulative encounter duration averaged per encounter at each discrete time interval (30 minutes) before and after the reference time 0 point.

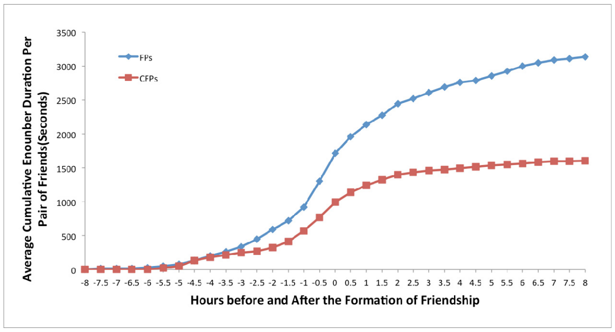

Figure 2. Cumulative encounter duration averaged per encounter over time for friend pairs (FPs) and user pairs who share common friends (CFPs).

The average cumulative total encounter duration curve can be divided into three phases.

- *Phase I*. More than 3 hours before two users in a FP become friends, the average cumulative total encounter duration is very small and rises very slowly. In the beginning, people do not meet much of each other in the room because they are probably outside of the room or if they do encounter, it is short due to them passing by each other to attend to an activity.
- *Phase II*. Around 3 hours before the FP formation until time 0 when the friendship is established, the average cumulative total encounter duration rises sharply to be considerably large. As shown in Figure 1, before the time of friendship formation, the average cumulative total encounter duration increases rapidly with time. This indicates that right before two users add as friends with each other, they are spending more time to be physically proximate to each other.
- *Phase III*. After time 0, the average total encounter duration decreases which causes the cumulative average total encounter duration curve to stabilize and flatten out. This indicates that after the social connection has been established, the users spend less time being physically proximate to each other. Most likely this is because after the user adds this person to her friendship network, she proceeds to meet others, therefore there is no need to be physically proximate to that person.

The above results suggest that more physical proximity encounter duration results in a higher possibility to add another as a friend. This agrees with our hypothesis (H1) for FP. However, the formation of the online friendship has a negative effect on the proximity encounter duration afterward, which is contrary to our hypothesis (H2). We believe the reason for this behavior in H2 is due to the user intention during the academic conference. In a conference, the objective is to meet more attendees. In the beginning (Phase I), you do not know many people so you can hardly add many friends. Then, in Phase II, as you begin to meet people, you start talking with them face to face, therefore

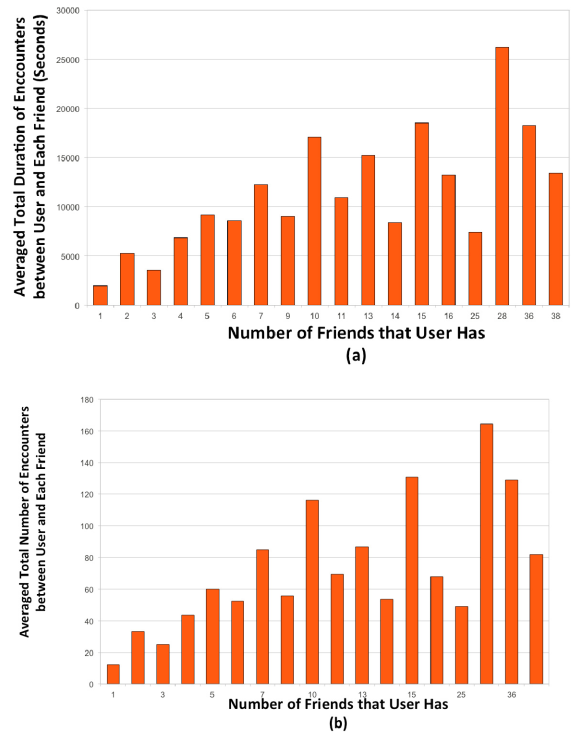

Figure 3. (a) Average total duration and (b) number of encounters between a user and each friend v.s. number of friends the user has.

your encounters with that person increase as well as the encounter duration, during when you want to add her to your friend network and make a record of this connection. In Phase III, you want to meet other people, therefore the frequency of encounters are less and encounter durations are smaller, because there is no need to be physically proximate to that person.

Second, we study the correlation between the number of friends a user has with the encounters of this user with all her friends. For a user u_i, we define the number of friends u_i has as n, and let $U(n)$ be the set of user ids whose friend number is n. Then let $T_{en}(e_{i,j}) = \int_0^{+\infty} \Delta T_{en}(e_{i,j}(t))dt$ and we calculate the total sum of encounter duration $\sum_j T_{en}(e_{i,j})$ and number of unique encounters $\sum_j e_{i,j}$ between u_i and all her friends $\{u_j : j \in F_i\}$, and then we get the average total encounter duration per user:

$$\overline{T}(n) = (\sum_{i \in U(n)} \sum_{j \in F_i} T_{en}(e_{i,j})) / (\sum_{i \in U(n)} u_i),$$

and average total number of encounters per user:

$$\overline{I}(n) = (\sum_{i \in U(n)} \sum_{j \in F_i} e_{i,j}) / (\sum_{i \in U(n)} u_i).$$

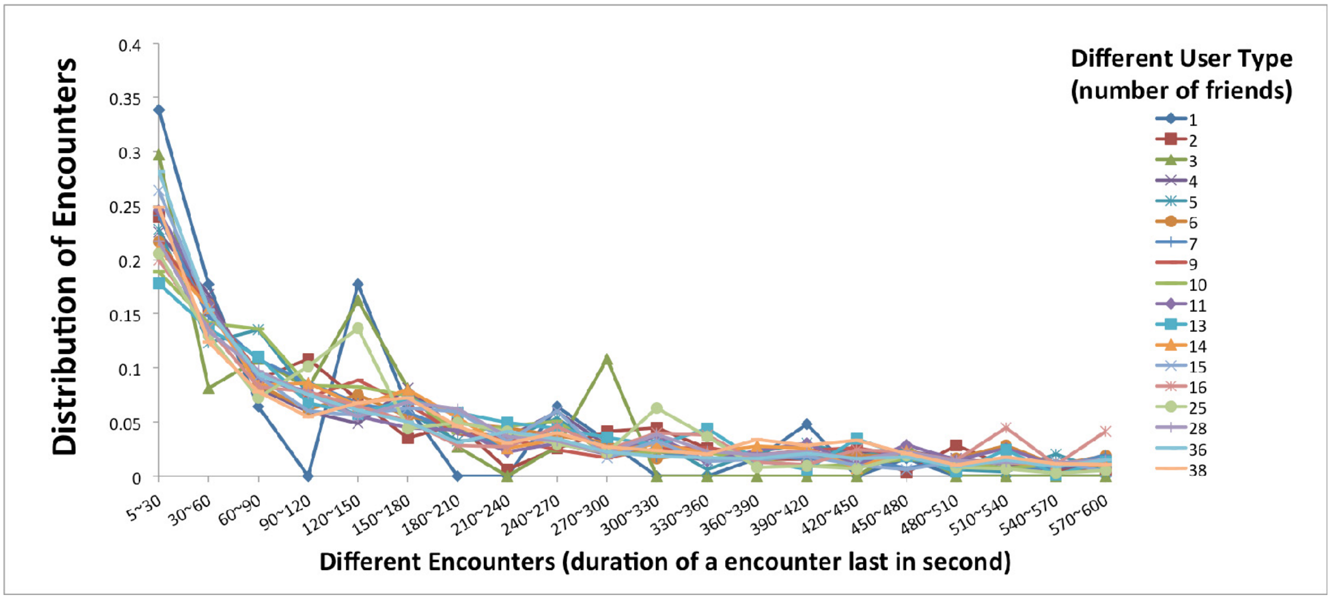

Figure 4. Distribution of encounter for different kinds for user (number of friends)

Figure 3 shows the value of $\overline{T}(n)$ and $\overline{I}(n)$ with different number of friends n.

The overall trend from Figure 3 is that as the number of friends that a user has increases, both the average total encounter duration and encounter number increase at the same time, despite the limited number of users in the trial. That is, the more friends a user has, the longer total duration and greater number of encounters this user will have with each friend. If more encounters with friends means more active interaction and a tighter link with friends, then those who have more friends online will tend to have more interaction with each friend on average offline. However, this does not affect the duration per encounter, i.e. no matter how many friends a user has, the duration of each encounter seems to be the same.

The last analysis for FPs is the distribution of encounter duration with respect to the different ranges of encounter duration for different users by the number of friends the user has. Here, we filter encounters with duration between 5 seconds and 600 seconds, and divide them into 20 groups with 30 seconds as the interval unit. Figure 4 shows the results.

From Figure 4, we can discover similar trends for different kinds of users. Most of the encounter duration lies between 5 seconds and 90 seconds, and with the increase of the encounter duration, the proportion of encounters reduce regardless of how many friends a user has. This shows that although users have different number of friends, if one encounter is examined, on average, the duration length of one encounter follows a similar exponential decreasing distribution.

Indirect Linking (CFPs) and Encounters

Like friend pairs above, we do a similar analysis between the formations of common friend pairs (CFPs) and encounters according to time, except that we provide a different definition of the origin time point 0. Suppose u_i and u_j has a common friend u_k, u_i and u_k became friends at time t_1, while u_j and u_k became friends at time t_2, and $t_2 > t_1$, then t_1 is considered the create time for becoming a CFP. For those CFPs that have more than one common friend, the time when the first common friend link is established is the create time for this CFP. Results are shown in Figure 2. We can see that the trend is similar to FPs with encounters, however the difference is that the value of encounter duration on the CFP curve is smaller than that of the FP curve, which means encounter has a stronger correlation with online direct linking (friends) than with indirect linking like sharing common friends. This indicates that being friends is a stronger link than just sharing common friends for two users, as users in FPs have more and longer encounters than users in CFPs.

Our second analysis for CFPs is concentrated on analyzing the different types of user pairs rather than different users in the analysis for FPs. In FPs analysis, we divided users into groups by the number of friends that they had, while for CFPs, a user can have different number of common friends with every other user, therefore, it is ambiguous and less meaningful to explore the CFP linking and encounters for every user. Otherwise, considering that CFPs can be classified by how many common friends the two users in this pair have, and that sharing more common friends indicates more similarity between the two users, we conduct an analysis of the encounter duration and distribution with respect to different type of user pairs defined by number of common friends.

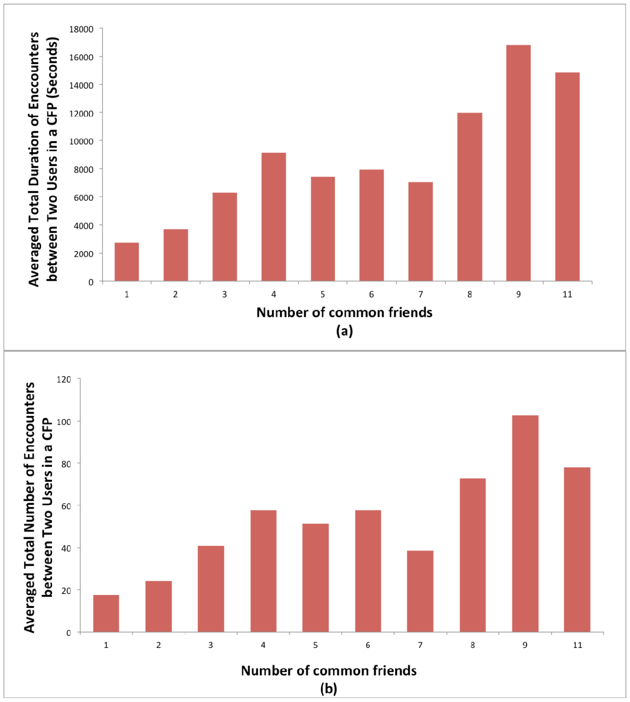

Figure 5. (a) Average total duration and (b) number of encounters between two users in a Common Friend Pair (CFP) v.s. number of common friends the two users have.

Let p_i be the i-th user pair who have common friends and $P = \{p_1, p_2, \ldots\ldots, p_N\}$ be the set of unique pair ids for CFPs, and let $e_i'(t)$ be the encounter occurred between the two users of p_i at time t with encounter duration as $\Delta T_{en}'(e_i'(t))$.

For a common friend pair p_i, we define the number of common friends as a variable m, and let $P(m)$ be the set of pair ids whose common friend number is m. Then let $T_{en}'(e_i') = \int_0^{+\infty} \Delta T_{en}'(e_i'(t))dt$ be the total sum of encounter duration and let $e_i' = \sum_{t=0}^{\infty} e_i'(t)$ be the total number of encounters between users in p_i during the whole event, and then we calculate the average total encounter duration per pair in this type $\bar{T}'(m) = (\sum_{i \in P(m)} T_{en}'(e_i')) / (\sum_{i \in P(m)} p_i)$, and average total number of encounters per user $\bar{I}'(m) = (\sum_{i \in P(m)} e_i' / (\sum_{i \in P(m)} p_i)$. Figure 5 plots the value of $\bar{T}'(m)$ and $\bar{I}'(m)$ with different number of friends m.

The overall trend is that as the number of common friends that a pair of users has increases, both the average total encounter duration and encounter number will increase at the same time, despite the limited number of users in the trial. That is, the more common friends a pair of users have, the longer total encounter duration and greater number of encounters these users will have with each other. If more encounters with other users means more active interaction and a tighter link with them, then those who have more common friends online will tend to have more interaction with each other on average offline. However, this does not affect the duration per encounter, i.e. no matter how many common friends two users have between them, the duration of each encounter seems to be the same.

The last analysis for CFPs is the distribution of encounter duration with respect to the different ranges of encounter duration for different user pairs by the number of common friends the two users have. Similar to analysis for friend pairs (FPs), we select encounters with duration between 5 seconds and 600 seconds, and divide them into 20 groups with 30 seconds as the interval unit. Figure 6 shows the results.

From Figure 6, we can discover similar trends for different types of user pairs. Most of the encounter duration lies between 5 seconds and 90 seconds, and with the increase of the encounter duration, the proportion of encounters reduce regardless of how many friends a user has. This shows that for those CFPs, although two users have different number of common friends, if one encounter is examined, on average, the duration length of one encounter follows a similar exponential decreasing distribution. This is similar to the previous results in the analysis for users with different number of friends.

To sum up the two studies of friend pairs (FPs) and common friend pairs (CFPs), we can see that larger encounter duration indicates high possibility of formation of both social links. And tighter social links, i.e. having more friends or sharing more common friends will result in more encounters, longer duration and high encounter duration, but do not affect either the average length or distribution duration per encounter. It is important to note that we do not claim that encounters did in fact cause two people to become FPs or CFPs because we did not study the intention of why users added a friend.

CONCLUSION

Find & Connect is an indoor location-based mobile social networking application applied at an academic conference. Find & Connect not only provides navigation function by implementing personal conference schedule and resource management on mobile phones, but also offers diverse means for users to establish and maintain social links in a conference or meeting event. Find & Connect collects and records the indoor location data of all users through a WiFi positioning system.

Our research problem was to explore whether there is any correlation between users' online social linking and physical proximity in an indoor location-based mobile social networking application. From the data that we collected at the conference, we used encounter as a

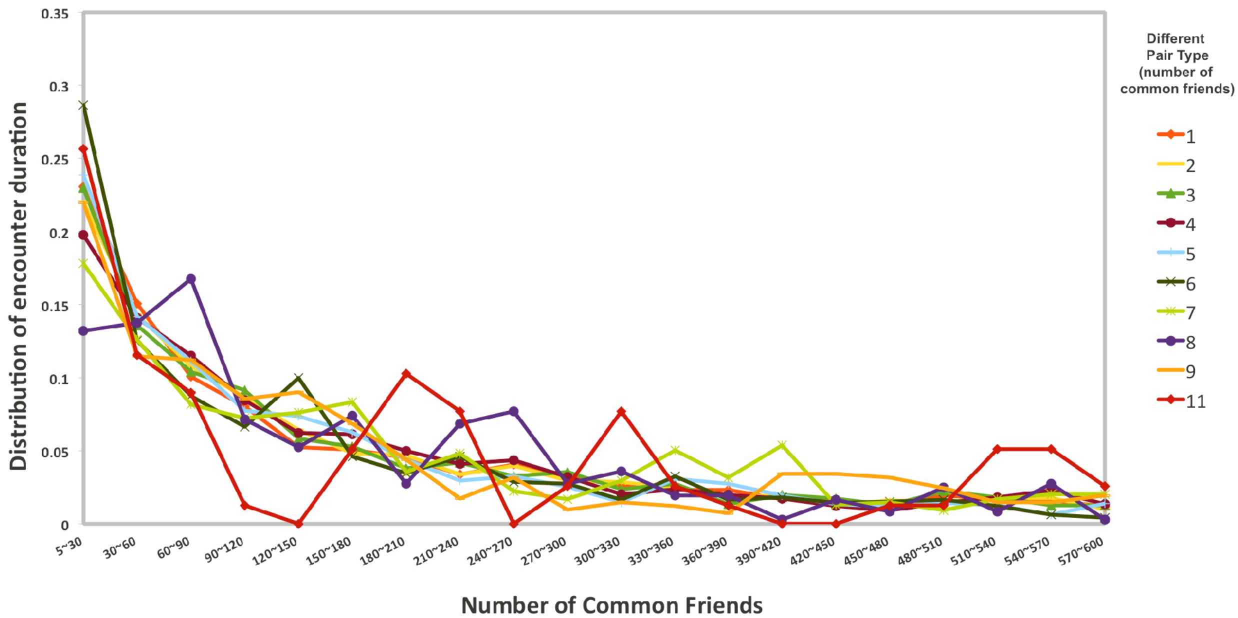

Figure 6. Distribution of encounters for different kinds for common friend pair (by number of common friends)

quantitative parameter to represent users' physical proximity, and we chose friendship (1 hop) and sharing common friends (2 hops) as two kinds of social links and explore their relations with encounters.

We find that (1) before online social links are committed, increasing proximity encounters cause a high probability for users to establish online social links between them, while after the links are established, increment of encounter duration becomes lower along time. (2) For two kinds of social links, friendship has a stronger correlation with encounter than just sharing common friends. (3) Higher sociality of a user, i.e. having more friends, indicates being more active in offline interaction, i.e., having more and longer duration of physical encounters with each friend; while, for a pair of users who are not friends, higher similarity of two users, i.e. sharing more common friends, indicate more physical encounter interaction between them. (4) Sociality of users and similarity between a pair of users do not affect the distribution of duration of each encounter, that is duration of each encounter is averagely independent with users' online social activities. These results imply that frequent indoor physical proximity interactions result in an increasing probability of creating online social connections, while after establishment of such online social connections, a higher social and similarity of users in their online connections results in more physical proximate interaction.

Our work is limited in that the chosen variable *encounter* is an interaction that only exists between two users, while in most scenarios, people have activities in groups, so we may miss some offline patterns of users' proximate interactions. Therefore, our future work includes solutions to detect patterns in a group of users, as well as a recommendation system applied with our results.

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