Physical Proximity and Online User Behaviour in an Indoor Mobile Social Networking Application

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***Abstract*—This paper studies the encounter patterns and online connections of 76 users in an indoor location sharing and online interaction social network application, to seek underlying relationship between users' offline behaviors and online social behaviors. We create an indoor location and proximity-based mobile social network system called Find & Connect that collects and records current indoor location of users and then enables users to generate and maintain their online social relationships. We obtain quantitative data which presents properties of users' online behaviors and offline behaviors, and then perform a user study to verify the utility of Find & Connect applied in large meeting events. Using quantified parameters, particularly, *encounters* regarded as representation of offline behaviors, and *exchange contacts* and *follow* as main kinds of online behaviors, our study shows a positive effect by offline behaviors on online social behavior, while a negative effect by online social connection establishing on afterwards offline social interaction. We also find that according to different kinds of online behaviors, their correlation with offline interaction resembles but has diversity in intensity.**

Keywords-social computing; social network analysis; indoor positioning; social behavior; physical proximity

I. INTRODUCTION

Ubiquitous usage of GPS-enabled mobile phones boosts the popularity of location-based applications like Foursquare and Gowalla. Rather than have social connections only on a social network site, with these applications, users are experiencing new means of social interaction related to their physical location, and are receiving help along in the process, such as for example, finding the location of a friend or a place [8, 16].

Aside from normal mobile phone users, these applications and services are drawing an upswing attention of researchers who regard these location-based systems on the mobile phone as new tools to study some sociological problems that used to be ambiguous due to the lack of quantization analysis methodology. As those applications have an online social networking structure like adding users as friends or following others to get their latest updates of various information, some researches focus on the relationship between the offline behaviors which can be inferred at least partly by users' location in the physical world, and the online behaviors that occur from the social features created by the application.

Yet, most of these applications mainly use GPS positioning modules on the mobile phone to get the physical location, which determines that all these location-based online services that the applications provide, are mainly focusing on a user's outdoor physical activities. Few social applications or services are available at a room level granularity when the applied scenario is in an indoor environment. Therefore, aiming to leverage management of physical resources like meeting rooms through event scheduling to facilitate social linking for connecting people, we create an indoor location and proximity-based mobile social network system called Find & Connect using WiFi positioning technology to provide users the opportunity to obtain indoor-based location and to meet with people they have never met before. Due to the different application contexts and scenarios, we believe that an indoor location-based solution has unique characteristics with respect to outdoor location-based solutions, which previous research fails to address.

Therefore, we expect Find & Connect to be a tool to analyze the correlation between online social behaviors and offline physical behaviors for indoor scope, homogeneously with current outdoor solutions. Hence, our research problem is to study whether there is any correlation between users' online behavior and offline behavior, and if so, how that correlation influences.

To address this question, we first analyze the usage statistics on Find & Connect during our trial that launched at an internal marketing meeting called GCJK, to determine parameters to present users' offline physical proximities and online social behaviors. From the results of usage analysis, we use encounters as a measure of physical proximity and select behaviors of exchanged contacts and follow as the representative delegates of the whole online social behavior. We then study the correlations between those parameters. Our previous work [19] also conducted a usage analysis but in the context of a multi-track large conference, whereas in GCJK, it was a single-track large meeting event. In [11], we did a study on social selection and social influence on online friendship to find the interplay between them, but did

not focus on the other online social behavior of follow and exchanged contacts.

Results of our usage analysis show that Find & Connect promotes users' interactions and communications in the real world. We discover that a tighter connection exists with encounters, compared with follow and exchange contacts, and by analyzing when these connections are established, they centre around the activities in the event. Results of the correlation study show that, (1) before online social connections are established, more offline social behaviors and interactions result in an increased probability for a user to establish online social connections with another; and (2) after above online connections are established, more online social interactions or behaviors result in a decreased duration and frequency of offline interactions between each other. We also explored that, of the two online behavior parameters, follow behavior has a much stronger correlation with offline behaviors than exchange contacts. This suggests that in events similar to GCJK, follow seems to be a stronger tie between users than exchanging contacts, because follow entails tracking a user's updates whereas exchange contacts just means you exchange business card information for the primary purpose of connecting offline.

The rest of the paper is organized as follows. Related work is discussed in the next section. Then Section 3 describes our system overview and features of Find & Connect. Section 4 explains the theory and methodology behind physical proximity and online social connections. Next, Section 5 describes the usage analysis of the GCJK trial where we deployed Find & Connect, then quantitative results of the temporal relationship between physical proximity and online social connections (exchange contacts and follow) are presented in detail and the behind reasons are discussed. Finally, we conclude the paper in Section 6, followed by a discussion on the potential design implementations as well as future work.

II. RELATED WORK

A. Location-based Services

There is a boost in the number of location-based application and services due to the ubiquity of mobile device usage and mobile network coverage. For example, Home-Explorer [4] is designed to search and find physical artifacts in a smart indoor environment, while 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 in order to recommend relevant friendships that would be difficult for users to have obtained before. Besides these commercial applications or services, we also find an increasing number of services with research purposes, such as Intel's PlaceLab [14] and MIT's iFind [33], both of which focus on improving accuracy and its impact on the social network. Tsai et al [15] focused more on the impact of feedback with their location-sharing application. In Bakhuus et al's paper [17], they studied sharing location with each other in a group and how the awareness of location impacts their self-presentation, yet, they did not discuss impacts on the social network. WhozThat [1] is a system built on mobile phones to create a context-aware mobile social network, but does not utilize how location awareness offers facilities to users. These applications or systems fail to help users create and maintain their social network at the same time to bring convenience and facilities to users. To address this, we design and create Find & Connect that combines a user's location, social events and social context in the physical world, like in the workplace for managing workplace resources [21] or in the conference for enhancing conference participation [19]. We also utilize a user's physical proximity in the form of encounters to broaden a user's social connections by creating an online social network service that suggests people to connect to, based on location and encounter history.

B. Physical Proximity and Social Interaction

The next step beyond location-based services is to use position data collected by these location-based applications as an attempt to answer some sociological problems used to address the lack of efficient methodology or quantitative data. Among those studies, some promising results show that for those users of online social networks, underlying patterns emerge when combining their online behavioral interactions with properties of their offline behaviour before, during or after their online social connections are established.

To quantify users' offline behaviors, most of these researches regard a person's physical proximity as one representative social property of user behavior in offline surrounding contexts. Eagle et al. [29] use the location data they collected through GPS on a user's mobile phone and use proximity of the users at certain time like working hours, weekend and the number of co-locations, in order to present the properties of a user's offline location tracks. Some services use proximity encounters detected by radio frequency identification technology (RFID) or Bluetooth, and use the frequency of proximity as friend recommendation evidence such as Aka-Aki [3]. Others use proximity encounters to introduce people and infer a user's social network like Serendipity [18]. Considering that GPS positioning methods [12] have accurate limits (on the order of 50 meter error) that cannot omit the noisy proximities when no interaction is happening, outdoor co-location does not always infer the interaction. We believe that collected proximities from Find & Connect obtained through a WLAN-based positioning system [20, 26] can better present or infer the offline interaction between users.

To understand social interaction, a classification is given: social selection [14, 22] and social influence [6]. Homophily principle [22] in the formation of network structures and ties, presents that we tend to connect with similar people and be friends with them. The intrinsic homophily between

individuals such as similar characteristics, interests and beliefs, and the surrounding context factors like studying in the same school, have been validated to contribute to the usual preferential ties [14, 22]. The fact that people form social ties based on certain same characteristics they possess is often termed social selection [22]. In social selection, people may have more opportunities in the social environment to form friendships with other like-minded individuals, due to the shared characteristics [10, 29]. While in social environments, people not only tend to friend with like-minded individuals as indicated by the social selection principle, but they will adapt their activities and behaviors to be accorded with that of their friends, which is called social influence. Social influence exists in almost every area, from daily life to adopt smoking [2] and losing weight [7], to virtual goods purchases [28], consumer's desires and behaviors and technology adoption [31]. Especially in online social networks and communities, people's probability of joining a community in LiveJournal [31], editing a Wikipedia article and attending a conference listed in DBLP [5], increases linearly as the number of their friends who are already there increases. The social influences in these works in people's social behaviors are all so strong that a set of friends is about 100 times more powerful in influencing a user to join a group than the same number of strangers.

Among those studies for underlying correlation between behaviors or interactions and offline proximity, work in [16] utilizes self-reported address data from Facebook users and their network ties to measure the relationship between geography and friendship. The authors find that in social selection, Facebook users' probability of friendship is roughly inversely proportional to their distance at medium to long-range scale, while in shorter distance scale; the probability is less sensitive to the distance. Work in [8, 25] use Bluetooth technologies to define the relative physical closeness and infer the friendship in social selection through encounter duration and frequency. These works choose relationships that have already been established and claimed by users themselves on online social networks, rather than inference from collected user communications records, which is not promising as frequent communication may result from other surrounding contexts such as colleagueship rather than real friendship. Moreover, these works do not study social influence on physical proximity after social selection is committed. For example, does the physical proximity interaction in a shared physical environment increase if two people establish an online relationship? Exploring this is important to help to bridge the gap between physical offline co-location and friendship in the online world. For example, work in [12] studied the diverse location measurements and proposed location entropy to predict the friendship of two users by analyzing their co-location trace, which addresses some different problems. Therefore, in this paper and with Find & Connect, we explore this problem but within an indoor location environment. The next section describes the system and features of Find & Connect.

III. FIND & CONNECT: SYSTEM DESCRIPTION AND FEATURES

In this section, we explain Find & Connect, a platform that we built for providing social networking amongst attendees at a conference or meeting, for addressing our research questions. We first provide a system overview and then explain the features that we created for social networking.

A. System Overview

Find & Connect provides an integrated interface on the mobile phone to bridge the gap between online social networks among people and physical interactions like proximity and offline resources, like sessions at a conference or meeting event. As an indoor location-based social networking application, Find & Connect uses WiFi to set up a positioning system that records the updated locations of all the users by the positioning client installed on the mobile phones carried by the user, and records this location data. Thus, every time a positioning client updates location, the positioning server can calculate and record the physical proximity between the user and other online users.

A web application is built to present the location-based social network services in a mobile web browser on the mobile phone where the positioning client above is installed. The web application sends requests to and receives responses from the Find & Connect application server, which not only processes application data corresponding to feature requests on our web user interface, but also communicates with the Find & Connect positioning server to provide the physical proximity interactions between meeting attendees and also show where users are.

Detailed description on the Find & Connect system architecture can be found in our previous paper [19].

B. Social Features

To help users to easily establish new social connections at a meeting event and find useful physical resources during the event, several social features and services are created. Presenting all the social features on the web application running in mobile web browsers, Find & Connect not only provides the basic functionalities to make the meeting participation much easier by showing the attendees' physical locations in the meeting room, but also bridges and connects the attendees by helping to build the social links among the attendees through diverse channels. We show the user interface which was implemented for an internal meeting called GCJK in Figure 1.

1) Home screen

As shown in the Home screen in Figure 1 a, for Status feature, users can post and edit their latest status and share their status with other users of Find & Connect; and the Map feature shows the location of the current user and also

other online users whose privacy setting allows location sharing (set by selecting the Privacy button). In the Profile feature, users see and edit their detailed profile information. In the Network feature, it shows a user's established network, including "Contacts Exchanged", "Following", "Following Me", and "Encounters". Finally, in the All Updates feature, users can view the updated activities of other users that the user has followed.

2) Profile screen

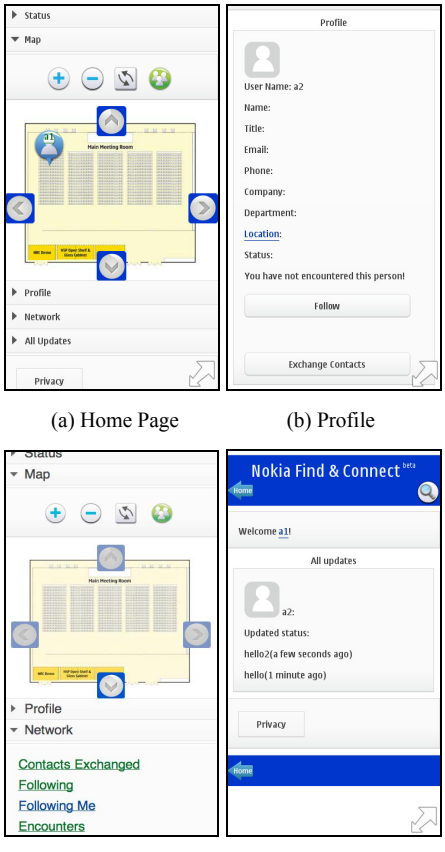
In the Profile screen, users can see their profile as shown in Figure 1 b and are able to edit the fields except for User Name, Status and Location. When users see a person on the map or search for the person, they can select the name and it will show the person's profile as in Figure 1 b. Users can interact with others through visiting each other's profile, sharing their location with others (who to share location with is governed by the Privacy), and viewing where others are and what others are doing now with the status (that users enter in the Status of the Home page in Figure 1 a). Then, users can connect to that person by exchanging contacts with each other (where both users will receive a business card of the other through SMS that corresponds to the profile information), and following that person similar to follow in Twitter. Find & Connect also shows whether users have encountered that person which then provides the incentive for either following or exchanging contact with that person. We describe the details of how a person encounters another in the next section.

3) Network screen

In the Network feature as shown in Figure 1 c, users can view the social networks they have established. Selecting "Contacts Exchanged" will show all the users that a specific user has exchanged contacts with. By selecting "Following", it will show all the users that the user has chosen to follow. Selecting "Following me" will show all the users who have chosen to follow the user. Selecting "Encounters" will show all the users that have been in close proximity with this user. In GCJK, if two users' locations are within 4 meters, this proximity will be recorded, and the users will be shown here. Generally, the Network feature is designed to present an aggregated list of all the users that a specific user has a relationship with.

4) All Updates screen

In the All Updates screen as shown in Figure 1 d, a user can view all the updates of the users that she follows with. For each followed user, she can see the status history, the people that she follows, as well as the people that she has exchanged contacts with. The premise of having this screen is similar in motivation to the Wall feature in Facebook where it provides a feed of all the updated interactions from the user's contacts, from which she can follow their activities and also provides another avenue to make connections with others. The next section will explain about the physical proximity and online social connections in Find & Connect and how the two are integrated and influence each other.



(a) Home Page (b) Profile

(c) Network (d) All Updates

Fig. 1. Client user interface of Find & Connect in GCJK

IV. PHYSICAL PROXIMITY AND ONLINE SOCIAL CONNECTIONS

At any physical event, we have two types of social interaction: offline (physical) and online (virtual). Location-based applications can and do help to bridge this gap between offline and online, and can record and track a user's physical location which makes it possible to study a user's offline activities and their relationship with online activities [12]. However, the problem is that the applications are primarily based on GPS location data whose positioning accuracy is within at least 50 meters, the data only records co-location, and cannot be used to record any intense interaction especially indoor activities. We need to record whether users are physically proximate or close with each other as well as their context in order to infer the activity. By doing so, we can record offline social interactions.

On the other hand, establishing online social connections, such as adding a friend, is performed manually. For example, currently, I need to remember to add a person I just talked with from a conference session to Facebook, rather than the system automatically suggesting that I should add this person on Facebook because it knows I was talking

with him (note, it is difficult to say that you are talking with another, but we can at least infer that you are doing some offline communication if we detect you are close to another for an extended period of time). Therefore, the connection between offline and online currently is not seamless. However, if we record the physical proximities of people with each other, then we can attempt to capture the opportunities where people that meet each other in real life, can also be reflected online so they can still continue their relationship.

Motivated by the work of [12] where they discovered that users that are co-located together tend to have more online social interactions in Facebook, we also examine whether users that have more physical proximities with others in indoor environments, will enable more online social interactions.

A. *Physical Proximity*

In Find & Connect, we define a parameter called *encounter* to denote physical proximity. That is, if a pair of users start to be physically near within a certain distance threshold (called the encounter distance threshold) and stay for a certain period of time (called the encounter duration) before they move away again, we call this an *encounter*. For any pair of users that are on the same floor at a particular point in time, every 5 seconds we compute the distance between the pair and if the distance is less than a specified encounter distance threshold, then we record it as a possible encounter. Then, we compute the distance again, and if we discover that the pair distance 5 seconds later is also within the encounter distance threshold, we record it still as the same encounter. We repeat this process for all combinations of pairs of users on the same floor. The encounter duration is calculated as the difference in time that the distance between the pair becomes greater than the encounter distance threshold, and the time that the distance between the pair is firstly within the encounter distance threshold.

B. *Social Selection and Social Influence*

In Find & Connect, people have opportunities to form relationships with other like-minded individuals, due to the shared characteristics that they have such as common friends, similar profile, and common encounters. If you physically encounter a particular person more and have longer encounter duration, then this may increase the probability that you will follow this person and also exchange contacts with them. The reason why is because there is an attractive force of similarity between the two of you, the similarities being that the two of you are at the same place at the same time doing some same activity. In other words, social selection is at play which will influence your behaviour to want to establish a social connection with that person, which you also want to reflect online by following and exchanging that person's contact.

In addition, social influence is at play where users adapt their activities and behaviors to be accorded with that of their friends. In the GCJK meeting, we study for social influence whether contacts that are exchanged or people that users follow, will result in increased physical proximity encounters between each other. In other words, if I follow you or have exchanged contacts with you, will I encounter you even more because I want to have more offline social interactions with you?

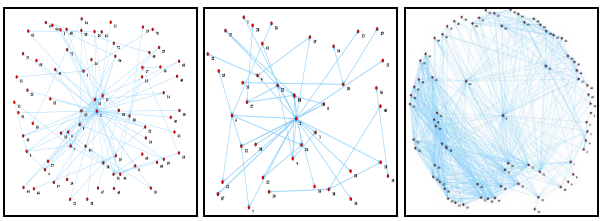
Our hypothesis is that: (1) for social selection, more physical interaction, here measured by encounters, will result in an increased probability for a person to create new online social connections in Find & Connect (i.e. to exchange contacts or to follow someone), and (2) for social influence, once an online social connection is established, (i.e. contacts have been exchanged or someone has been followed), will result in an increased frequency of encounters and encounter duration between each other. The next section will explain about the trial and experiment for testing out the hypotheses.

V. TRIAL OF FIND & CONNECT IN INTERNAL MARKETING EVENT

Find & Connect was deployed at an internal marketing event (called GCJK) for one day at the main meeting room of a conference hotel with WiFi access points placed in various locations in the room. The marketing event was single track and divided into 19 activities where the talks in each activity (if there was any) were held in the centre of the meeting room, and concurrently, there were demos shown outside of the centre area. Users were encouraged to download and use the Find & Connect client throughout the event. We first perform a user behavior analysis of the online social interactions recorded at the event, followed by a correlation analysis between encounters and the social interactions.

A. *User Behavior Analysis*

A total of 779 people pre-registered for the trial from which 76 users downloaded and used the client. In our database and log, we recorded the profile, exchanged contacts, followers, encounter information, status, and location for each user. From this data, we analyze the various social networks formed from the social interactions of



(a) follow (b) exchange (c) encounters

Figure.2 Visualization of three networks in the Find & Connect GCJK trial

follow, exchange contact and encounter relationships arising in Find & Connect. We also analyze the location distribution of the users.

1) Follow Network

The follow network is a form of social interaction network which comprises of all users that follow others and others that follow that user. A total of 72 users are in the follow network with 123 follow links generated, 27 unique users follow others and 66 unique users are followed.

We perform a network analysis of the follow network for all registered users and report the results in Table 1. Figure 2 a shows the visualization of the follow network.

2) Exchange Contact Network

From the acceptance of exchange contact requests, we discover 41 users in total who have at least exchanged contacts with one person in the exchange contact network and 51 exchange contact links are generated. There are 16 contacts that are exchanged in the day before the event, 2 are exchanged in the morning before the first activity and 33 are exchanged during the activities. The distribution of the 33 contacts exchanged in the 19 activities is shown in Figure 3.

As expected, the majority of contacts are exchanged during the activities in the main meeting room, with the most during the Lunch and Demo experiences (Activity 8) and Power of Innovation activity (Activity 9). We discover that people mostly exchange contacts not during the actual main talks, but after, during lunch and leisure time. We perform a network analysis of the exchange contact network for all registered users and report the results in Table 1. Figure 2 b shows the visualization of the exchange contact network.

3) Encounter Network

Whereas follow and exchanged contacts are online social networks, the offline social interaction network is the encounter network which comprises of all users that encounter at least one person. A total of 70 users are in the encounter network with 592 encounter links generated. The social network properties of the encounter network are shown in Table 1.

Figure 2 c shows the visualization of the encounter network.

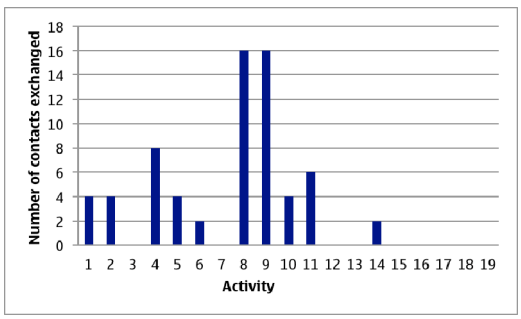


Figure 3. Number of contacts exchanged during different activities

4) Location Updates

From the trial, a total of 76 users uploaded 6632 locations. Figure 4 shows the distribution of the location updates by every user which appears to follow an exponentially decreasing distribution with the head of the distribution (less than 5 users) having an excessive amount of location updates, and the majority in the long tail having less than 100 location updates. Aggregated positioning of users and their locations in the main meeting room is shown in Figure 5 and if we overlap the scattered dot patterns to the meeting room map, we see that the aggregated positioning points correspond to the activities going on, that most people were in the center of the room where the talks were held, and it actually shows the setup of the environment for the talks (the aisles for the chairs) and where the demos were at. Therefore, aggregated positioning seems to be a good indicator of the density of activities that are happening.

5) Comparison Between Follow, Exchange Contacts and Encounter Networks

We can explore several differences between the online social networks (follow network and exchange contact network), and an offline proximity network (encounter network). These networks have distinguishable differences in structure. As shown in Table 1, the encounter network has similar number of users with the follow network, but has nearly 5 times the number of links as the follow network. Also, the encounter network has almost 2 times the number of users as the exchange contacts network, yet more than 10 times the number of links as the exchange contacts network. In addition, the encounter network has the highest clustering coefficient and highest density, which indicates that the encounter network is the most tightly connected. All these results show that the encounter network is better connected. Comparing the two online social networks, we observe that although the follow network is larger scale than the exchange contacts network, the follow network is less dense than the exchange contacts network. While the average clustering coefficient and network diameter are quite the same, this means that the exchange contacts network and the follow network have equal level of connection ties, while the follow network is larger than the exchange contacts network.

Overall, in terms of highest density and smallest average shortest path length, the order is encounter, exchange contacts and follow network which intuitively makes sense because there are many encounters between people (recorded

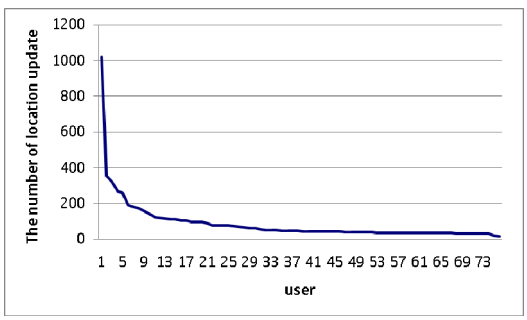


Figure 4. Location updates by Every User

automatically), compared with exchange contacts and follow which are manual. We can also see that the size, connectivity and density as reflected in the visualization in Figure 2, also confirms the order of the network.

B. Correlation Between Physical Proximity (Encounters) and Online Social Connections

We now address whether there exists a relationship between physical proximity and online social connections. From the trial, we want to see whether having greater encounter duration with a user will increase the probability of following that user or having an exchange contact with that user. We choose up to 4 meters to define an encounter based on former study of Proxemic Behaviors [9].

Both the time when the followship is created (when the follow request is sent) and the time when a pair of users have exchanged contacts (when the exchange contact request is sent) are recorded and are used as the origin point (time 0) of the time axis with 30 minutes as the unit interval. Depending on the social relationship of a user pair, we divide all user pairs into two types, those who exchanged contacts, denoted as Exchange-Pairs; and those who established followship between each other, denoted as Follow-Pairs. Similarly, encounters of all user pairs can be divided into two categories: encounters of Follow-Pairs, denoted as Follow-Encounters; and encounters of Exchange-Pairs, denoted as Exchange-Encounters.

For each of the user encounter pairs (Follow-Encounters and Exchange-Encounters) we sum out their cumulative duration value of their encounters in discrete time intervals before and after their respective behaviors were committed, and then average them by the number of this type of user pairs, which results in the Cumulative Average Total Encounter Duration for any pair of users. Figure 6 shows the cumulative total encounter duration averaged per pair of encountered users at each discrete time unit (30 minutes) before and after the time 0 point, for follow and exchange contacts, and for four different encounter distance thresholds.

We can see similar trends for follow and exchange contacts when the encounter distance threshold varies from 1 meter to 3 meters. The trends can be divided into three phases.

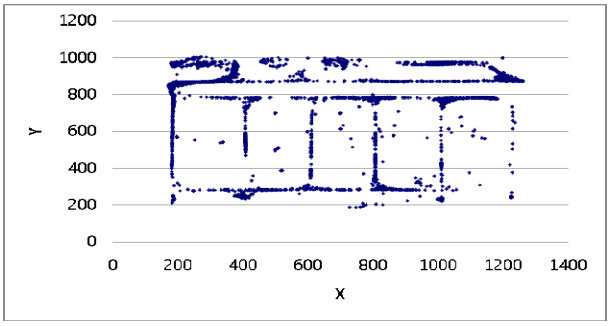


Figure 5. Aggregated positioning of users in the meeting room at the GCJK event.

- Phase I. More than 2 hours before any online social interaction request (exchange contacts or follow), the cumulative average 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 2 hours before the online social interaction request until time 0 when the online social interaction request is sent, the cumulative average total encounter duration rises sharply to be considerably large. As shown in Figure 6, before the exchange contacts request or follow request, the cumulative average total encounter duration increases rapidly with time. This indicates that right before two users exchange their contacts or follow each other, they are spending more time to be physically proximate to each other.
- Phase III. After time 0 when the online social interaction request is sent (exchange contact or follow), 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 user finishes pressing the Exchange Contacts or Follow button, the social connection has been established, and the users spend less time being physically proximate to each other. Most likely this is because after the user adds this person to her social network, then she can easily see the person's social activity updates from the All Updates page of the Find & Connect application, so there is no need to be physical proximate to that person.

The above behavior is similar to that of friend requests from our earlier work [32]. This suggests that the social selection on physical proximity in exchange contacts and follow is strong (Phase II), however social influence is weak (Phase III). This agrees with our hypothesis (1) that more physical proximity encounter duration results in an

TABLE I. COMPARISON OF FOLLOW NETWORK, EXCHANGE CONTACT NETWORK AND ENCOUNTER NETWORK

	Follow network	**Exchange contacts network**	**Encounter network**
# of users	72	41	70
# of links	123	51	592
Average # of users followed, exchanged or encountered	1.7083	2.5	8.457
Network density	0.02406	0.062195	0.245548
Network diameter	6	6	4
Average clustering coefficient	0.221	0.195	0.683
Average shortest path length	2.7827	2.6229	2.01656

increased probability for a person to follow another one, or exchange their contacts with. However, contrary to our original hypothesis (2), after users have established an online social relationship, the probability of users being physically proximate to each other decreases. We believe the reason for this behavior is due to the user intention during the business meeting or event. In a business meeting or event, the objective is to meet more people. In the beginning (Phase I), you do not know many people and there is no online social selection. Then, in Phase II, as you begin to meet people, you start talking with them face to face, therefore your encounters with that person increase as well as the encounter duration. As you begin to know more about that person, you want to add her to your social network and therefore you choose to either follow or exchange contacts to make a record of this connection. Social selection is at play here. After that, 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 since you can follow their updates in the application. Therefore, social influence is weak here.

An alternative explanation is that if user X just wants to get a business card of user Y, user X will spend less time in close proximity with user Y than the case when she wants to follow user Y. Therefore, this indicates that followship appears to be a much stronger link between users in a user pair than exchange contacts, because people tend to spend more time in proximity when wanting to follow since they are curious to see where the person they are following is. People tend to follow a person if they have spent more time in proximity distance of each other. For exchanging contacts, users just get the business card so they already have a mechanism for contacting each other in the future, therefore there is no need to be close any more which means they can move to meet another user.

Figure 6 demonstrates another similar trend that for encounters defined by different distance threshold, the Follow-Encounters duration line and the Exchange-Encounters duration line overlap until 1 hour before time 0 at the first part of Phase II, and then two lines start to be separated distinguishably. In Phase III, both the Follow-Encounters duration line and the Exchange-Encounters duration line tend to be stable, and Follow-Encounters duration stays considerably larger than Exchange-Encounters duration. Additionally, in Phase I, both lines stay low and rise a little. This indicates that although physical proximities have similar effect on both kinds of social selection (i.e. exchanged contacts and following), the intensions of the effort are distinguishable. Clearly, a following behavior being committed requires a larger duration of encounters. An explanation may be that at a

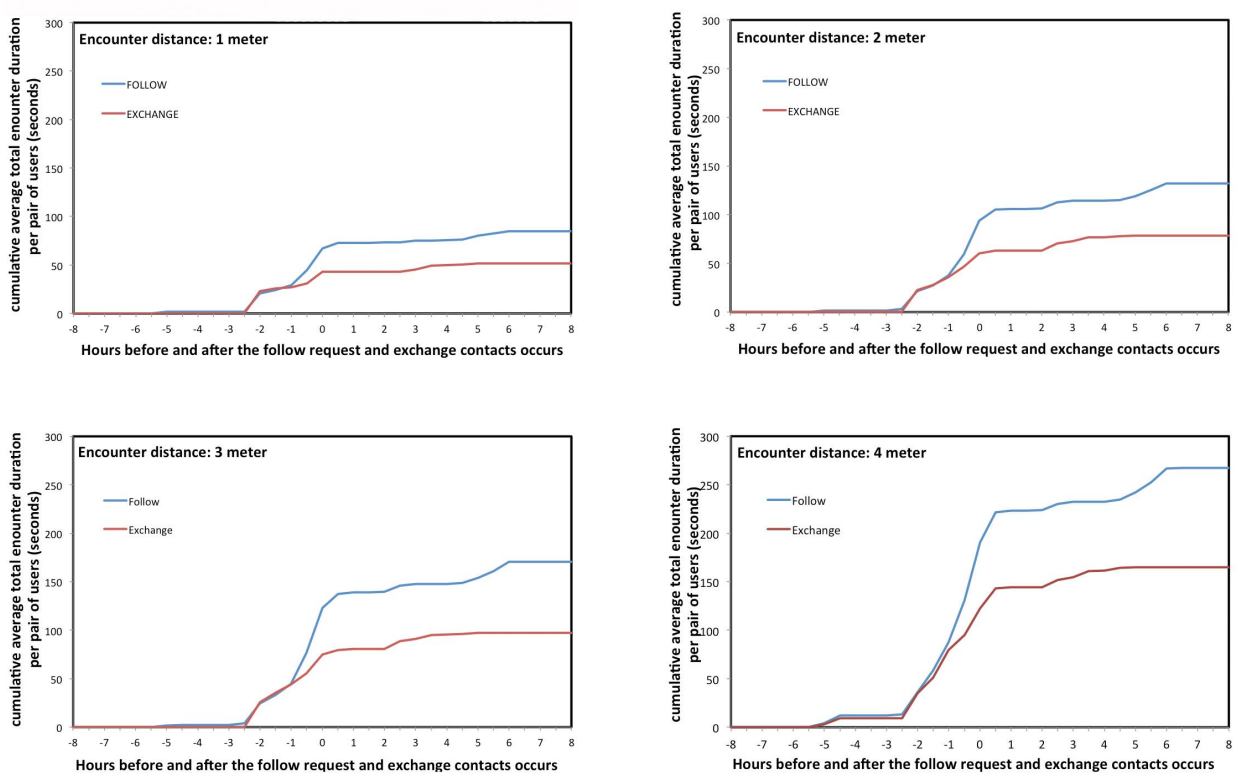


Figure 6. Cumulative total encounter duration averaged per encounter over time for different pairs of users

certain time length before a pair of users make online social selection, their encounter duration has little effect on their decision making, because they still have not been proximate long enough, which is demonstrated as the starting part of Phase II. If they have been proximate quite long, then they may choose to exchange contacts, yet if they have been proximate even longer, they may decide to follow, which is demonstrated as in the last half of Phase II.

C. *Correlation Between Encounter Frequency and Online Social Connections*

We calculate the average number of encounters per user pair in discrete time intervals, before and after their respective behaviors are committed, for different types of user pairs (i.e. follow and exchange contacts) and different encounter distance threshold settings. When changing the encounter distance threshold setting from 1 meter to 4 meters, the results present similar trends. Therefore, only the result for the case when the encounter distance threshold is 4 meters is shown in Figure 7. Before the follow request is sent, there are an increasing number of encounters on average per user pair. This indicates that social selection on physical proximity in terms of the average encounter frequency has positive effect on the user's decision of exchanging contacts or following which is in accordance with the results from the cumulative average total encounter duration in Figure 6. After the exchange contacts request or follow request, the average number of encounters clearly decrease, which indicates that both exchanging contacts and follow have negative effect on physical proximity in terms of the average encounter frequency, which is also in accordance with the results from the cumulative average total encounter duration in Figure 6. User pairs with followship established have more encounters than user pairs with contacts exchanged, being in accordance with the results from the cumulative average total encounter duration in Figure 6. Therefore, there is also obvious correlation between online social behavior and physical proximity in terms of the average encounter frequency.

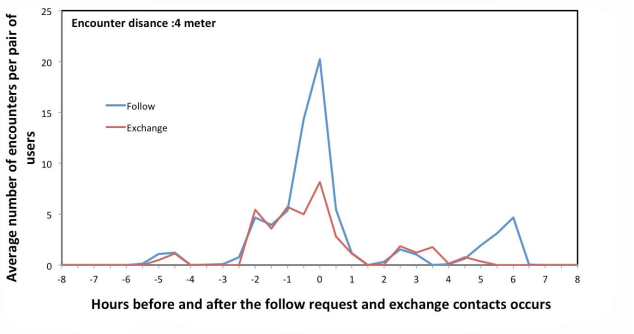


Figure.7 Average number of encounters per pair of users for Exchange Contacts and Follow

VI. CONCLUSION

Find & Connect is an indoor location-based mobile social networking application which not only provides navigation function 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.

Our research problem was to study whether there is any correlation between users' online behaviors and offline behaviors, and if so, what is the impact of that correlation in an indoor location-based mobile social networking application. We first conducted a usage analysis of a field trial of Find & Connect at a marketing meeting called GCJK to verify the utility of Find & Connect and then determined the parameters for representing users' online and offline behaviors in such applications.

Based on the results of usage analysis, we used the proximity data collected by the positioning system of Find & Connect and the online commitment behaviors in Find & Connect online social features, to investigate and understand the underlying correlation between offline physical proximity and online user behaviors. We defined a parameter called encounter to measure the physical proximity interactions between users and chose two main online social features (exchange contacts and follow) to delegate users' online behaviors, and then studied the correlation between the encounters and the online social features.

We find that (1) before online social behaviors are committed, more offline proximity encounters predicate high probability for users to exchange contacts between users and to follow users, (2) after online behavior is committed, both the duration and frequency of encounters decrease along time, and (3) follow behavior has much stronger correlation with encounters than with exchanged contacts. 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, more online social interactions or behaviors result in a decreased probability of offline physical proximity between users.

Our work is limited in that the parameters we chose only presented offline or online interactions between two users in a pair, whereas in many cases those interactions occur among a group of people. Our future work includes finding patterns of offline physical proximity in order to discover and record offline social interactions that can be converted into social connections in online social networks, as well as exploiting physical proximity in order to improve social recommendation systems to recommend people to establish a social connection with.

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