

Out of Sight Out of Mind – How our mobile social network changes during migration

Santi Phithakkitnukoon^{1,2}, Francesco Calabrese^{1,3}, Zbigniew Smoreda⁴, Carlo Ratti¹

¹SENSEable City Laboratory, Massachusetts Institute of Technology, USA

²Culture Lab, School of Computing Science, Newcastle University, UK

³IBM Smarter Cities Technology Centre, Dublin

⁴Sociology and Economics of Networks and Services Department, Orange Labs, France

Email: santi@mit.edu, fcarabre@mit.edu, zbigniew.smoreda@orange-ftgroup.com, ratti@mit.edu

Abstract—In this work we use anonymous telecommunication data to investigate how migration influences the dynamics of mobile social networks. We analyze the evolution of social ties for an entire country over a period of 11 months, examining: tie strength, sociality level, distance of ties, and persistence of ties. We find changes in tie strengths pre and post migration, specifically at six months before and a month after migration and discover that on average it takes approximately seven to eight months to restructure ones social network at a new residential location following migration. Moreover, the strongest ties such as those between families and close friends appear to be independent of migration. These ties continue to persist at nearly constant rates, in stark contrast to the weaker ties whose persistence rates drop significantly. Finally, we quantify the interdependency between the persistence rate, social strength, and migration distance; as a result, we are able to estimate how likely a given tie would persist, given the pre-migration social strength and distance of migration.

I. INTRODUCTION

Over the past few years datasets from cellular phone networks (e.g. call logs, phone tracking) have shown great promise for academic research, with data being used to explore human communications [1] [2], the geography of social networks [3] [4] [5], and urban dynamics [6] [7] [8] [9]. More recently there has been research into human mobility patterns [10] [11], specifically examining the regular movements that characterize our daily routine [12]. However, little or no work has yet been undertaken to explore one of the most disruptive ‘movements’ that characterize human life – i.e. residential migration.

In a seminal French study on land line usage, Mercier et al. [13] observed that residential migration affects telephone interactions as a function of the social anchor in the previous place of residency: the longer the residency, the greater the impact. In this paper we use cellphone data collected at the level of an entire country in Europe over a period of 11 months to detect residential migration and quantify its effects on the mobile social network. Is it true that distance tends to weaken our connections, as captured by the adage ‘out of sight out of mind’? If so, which parameters could help us quantify this effect?

Our work is framed by the theory of tie strength developed by Mark Granovetter in his 1973 milestone paper

[14]. Granovetter categorizes ties into two types: strong and weak. Strong ties are the people who are socially close to us and whose social circles tightly overlap with our own. Typically, they are people we trust and with whom we share several common interests. In contrast, weak ties represent mere acquaintances. Granovetter’s strong and weak tie concept [14] has motivated a number of studies ([15] [16] [17] [18] [19] [20] [21] [22] [23]). More recently it has been applied to the analysis of mobile phone social network analysis by Onnela et al. [1], who define tie strength as the aggregated duration of calls between two individuals. They found that weak ties were crucial for maintaining the networks structural integrity, whilst strong ties played an important role in maintaining local communities.

While our results focus on the mobile social network, we believe that they have broader relevance. Although mobile phone data captures just a slice of communication among people, research on media multiplexity suggests that the use of one medium for communication between two people implies communication by other means as well, especially for the closest relations [24] [25].

II. SOCIAL NETWORK AND MIGRATION

A. Dataset

In this study, we used Call Detail Records (CDR) of over 1.3 million mobile phone users (1,318,905) of 11 months between 2006 and 2007 from the whole country of Portugal. The CDR consists of following information for each call: Timestamp, Originating user ID, Terminating user ID, Call duration, Originating user cell ID, and Terminating user cell ID. This allows us to study both mobile social interaction as well as physical location of the users within the dataset. Note that the dataset does not contain information on text message (SMS) or data usage (internet).

Each user making or receiving a call is located through its connected cellphone tower (at the time the call was initiated). The total number of cell towers (tower IDs) is 6,509. Each tower serves on average an area of approximately 14 km², which is reduced to 0.13 km² in urban areas such as Lisbon. In accordance with [1] we

reduced the dataset to consider only reciprocal communications between users. By grouping together all calls made between the users, we derived a network of 11M edges (11,367,729 precisely).

B. Social Strength and Ties

We quantify social tie strength based on call duration (similar to [1]) as follows:

$$s(i) = \frac{c(i)}{\frac{1}{N} \sum_{i=1}^N c(i)}, \quad (1)$$

where $s(i)$ is the tie strength with tie i from the subject's perception, $c(i)$ is the total call duration with tie i , and the denominator is the average call duration of all associated ties where N is the number of associated ties. We classify ties with $s < 1$ as *weak ties* while ties with values of $1 \leq s < 2$ and $s \geq 2$ are classified as *strong ties* and *strongest ties*, respectively.

C. Migration

To detect migration, home location of each mobile phone user in our dataset must be determined. We identify home location as the cell location that the corresponding user has the most call activities during the night hours (10PM thru 7AM). Home location is then identified accordingly for each of 11 months. Social ties are thus estimated for each month based on call logs of respective month.

It appears that not all the users were active throughout 11 months, which leaves home locations of some months undetermined for a number of users. Therefore we select only fully active users for our study, which includes 110,213 users. Ideally, with the home location identified for each month, a migration can be simply detected as the change of home location. Since the home location is estimated with some degree uncertainty, the home location could be misidentified e.g. user is on a vacation, user is involved with phone calls where else more than at home, etc. As the result, we find a number of users have several changes of home locations throughout 11 months. We thus narrow down the set of our subjects to those whose changes of home location appear once with the (migration) distance of at least 50km. This, in turn, gives us 1,927 subjects.

Since different subjects migrated at different time, Fig. 1 shows the distribution of the number of migrations taking place during the course of 11 months. Note that data of October 2006 was missing (not provided to us from the telecommunication data provider), therefore we assumed continuation between September 2006 and November 2006 in our analysis. Due to the significant migration peaks detected in May '06 and March '07 that may have included people who did not migrate but temporary relocated, we therefore exclude them from our analysis and retain 492 subjects.

The distribution of the migration distance in kilometers (distance between old and new home locations) of our

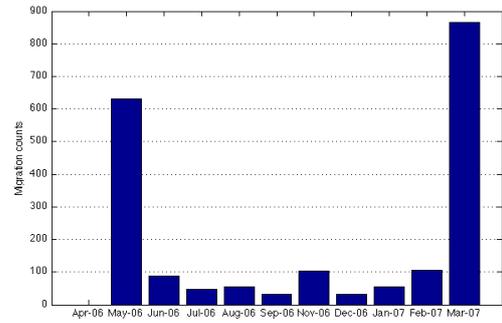


Figure 1. Distribution of the amount of migration detected from the 1,927 subjects.

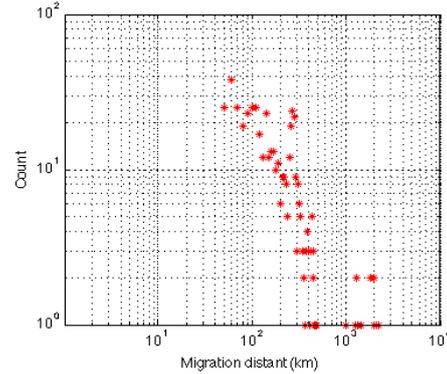


Figure 2. Distribution of migration distance (in kilometers) of the subjects.

carefully selected 492 subjects are shown in Fig. 2 – the distance is computed using Haversine formula.

The migration is shown on the map in Fig. 3(a) while a zoom-in version is shown in Fig. 3(b) where white lines are connected between the old and new home locations, with red and green circles represent old and new home locations, respectively. The detected migration is intuitive as majority of the migrations is directed toward the shore areas, and a large portion of the migration is between large cities such as Porto and Lisbon.

D. Evolution of Social Ties

Generally, social network evolves over time [26]. A special event such as migration can potentially impact the evolving social network. We thus explore here the behavioral change and evolution of social ties. To observe the dynamic of the social ties during the migration period, we construct a 4×4 -transition matrix, P :

$$P = \begin{bmatrix} p_{0,0} & p_{0,1} & p_{1,2} & p_{1,3} \\ p_{1,0} & p_{1,1} & p_{1,2} & p_{1,3} \\ p_{2,0} & p_{2,1} & p_{2,2} & p_{2,3} \\ p_{3,0} & p_{3,1} & p_{3,2} & p_{3,3} \end{bmatrix}, \quad (2)$$

where $p_{i,j}$ denotes the probability of going to from state i to j . The states are represented by social strength: *non-existent*, *weak*, *strong*, and *strongest* for $i, j = 0, 1, 2$, and 3 , respectively. The transition probability $p_{i,j}$ is defined as $p_{i,j} = n_{i,j} / \sum_{j=0}^3 n_{i,j}$, where $n_{i,j}$ is the number of ties whose tie strength (state) change from i in month $t-1$ to j in month t .

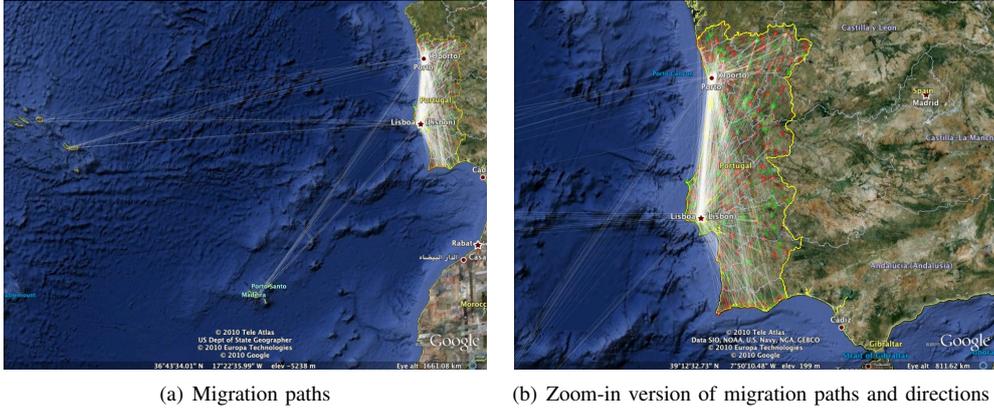


Figure 3. Migration paths and directions on the map. Migration paths are indicated by white lines and directions represented by red (old home location) and green (new home location) dots.

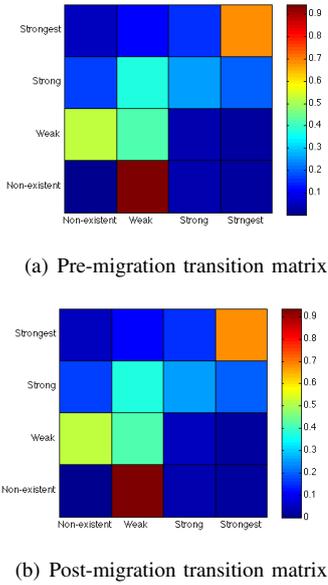


Figure 4. Transition matrix of before and after migration.

1) *Before and After Migration:* The first obvious thing one may explore is the transition matrix before and after migration. This allows us to see the different trends (if any) in social strength transition influenced by the migration. To do so, the matrix $N = \{n_{i,j}\}_{4 \times 4}$ is computed for each month t (for $t = 2, 3, 4, \dots, 11$) and for each subject. The transition matrices P_{before} and P_{after} are then derived from the sum of all matrices N 's (from all subjects) that belong to the pre- and post-migration period.

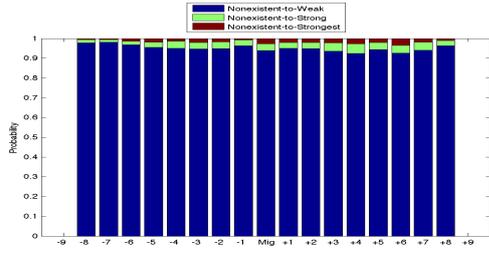
The P_{before} and P_{after} are shown with color plot in Fig. 4(a) and Fig. 4(b), respectively. It can be observed that the trends in transition remain the same for both matrices. The strongest ties tend to remain as strongest ties while strong and weak ties tend to shift down one step in social relationship more than maintain their strengths. Intuitively, the non-existent ties appear to mostly emerge as weak ties rather than jumping up two or three steps above in social strength.

2) *Transition during Migration:* No significant changes in social strength transition have been yet observed from pre- and post-migration transition matrices. We thus explore further into the chain of transition at month-by-month level across the migration period. Particularly, matrix N is computed for each month t and for each subject. These matrices are then combined with respect to the migration month t_{mig} where t_{-m} represents m months prior to the migration while t_{+m} on the other hand denotes the month that is m months after migration. Figure 5 shows the transitions over migration period of different states of social ties from which noticeable pattern emerges at t_{-6} and t_{+1} that reveals the tendency of decreasing tie strength as well as losing ties.

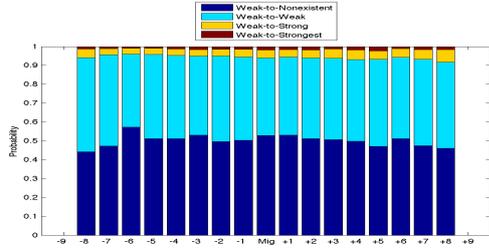
3) *Sociality:* As much as the change in transition matrices can reveal the socio-behavioral change influenced by migration, the direction of the change is also important. We explore further here the direction of the transition in social strength – moving upward or down downward in the state of tie strength. We simply quantify the leveling of tie strength as strongest tie = 3, strong tie = 2, weak tie = 1, and non-existent tie = 0. For each matrix N , we compute the total directional change of strength as

$$S = (n_{1,2} + n_{2,3} + n_{3,4}) + 2(n_{1,3} + n_{2,4}) + 3n_{1,4} - (n_{2,1} + n_{3,2} + n_{4,3}) - 2(n_{3,1} + n_{4,2}) - 3n_{4,1}. \quad (3)$$

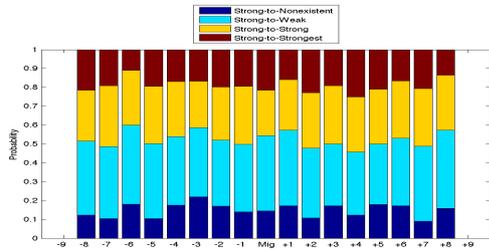
The higher S , the more active the subject is – socially. The value of S thus reflects the social activeness of the subject and hence it intuitively implies the sociality level. The result is shown in Fig. 6 where peaks are clearly observed at t_{-6} and t_{+1} , which is consistent with the previous observation of transitional changes. This also shows that people tend to become significantly socially inactive during the the sixth month prior to the migration and the next month after the migration – losing social relationships. Meanwhile, they tend to slightly more socially active during the forth month after the migration.



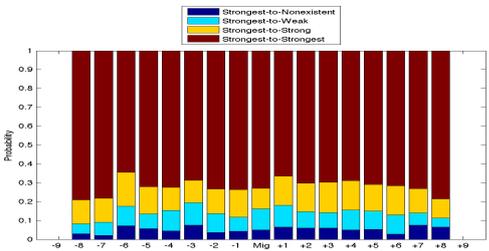
(a) Transition across migration of non-existent ties



(b) Transition across migration of weak ties



(c) Transition across migration of strong ties



(d) Transition across migration of strongest ties

Figure 5. Transitions over migration period of different states of social ties.

E. Distance of Ties

We further investigate the impact of migration to the dynamics of social circle. Migration introduces a change in physical distance to the social circle. How does physical distance of ties evolve over migration period? We compute the average distance of ties in kilometers and its standard deviation over the migration period – from t_{-9} to t_{+8} . The result is shown in Fig. 7 where the average distances are near 50km before migration and shifted up significantly once migration takes place (≈ 180 km). The average distance of ties then gradually decreases and reaches 50km territory again at the eighth month

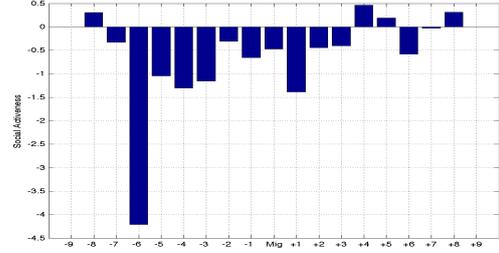


Figure 6. Social activeness level across migration period.

after migration. It can also be noticed that the variation (standard deviation) in distance is nearly doubled after migration. This perhaps can be explained by the fact that after migration takes place, the subjects still keep in touch with people in their old home areas while making new friends in the new home locations. Hence a big deviation in distances of ties. Evidently people tend to establish new ties in the new home locations as we can see from the decreasing average distance after migration that eventually reaches roughly 50km radius. The result implies that, on average, people take about seven to eight months to rebuild their new social circle in the new home locations after migration.

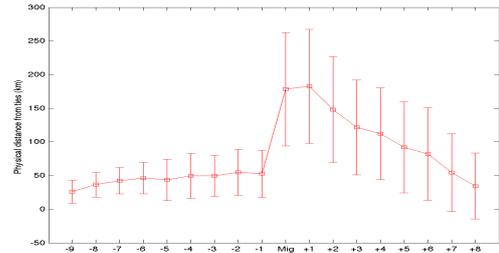


Figure 7. Physical distance of different social closeness over migration period.

F. Persistence of Ties

Ties at different social strengths may persist in different way over the migration period. To explore the impact of migration on persistence of ties, we use the subjects whose migration months are June '06 or later and derive social ties based on the first two months of call logs then observe the change in persistence rate of different tie strength over migration period. Persistence (Φ) is simply computed as the ratio of the number of common ties between the ties derived from the first two-month call logs ($M(T)$) and a given month m ($M(t_m)$), i.e., $\Phi = M(T)/M(t_m)$, where $t_m = t_{-7}, t_{-6}, \dots, t_{\text{mig}}, \dots, t_{+6}$.

As shown in Fig. 8, the strongest ties begin at t_{-7} with the highest persistence rate of close to 100% followed by strong ties at about 90% and weak ties at about 40%. The strong and weak ties' persistence rates drop significantly once migration takes place while strongest ties seem to be independent of migration (no such a strong drop observed). This implies that people tend to maintain their relationships with closest ties such as families and close friends regardless of physical distance. On the other

hand, ties that are not as strong tend to be more dependent of the physical distance as evidenced in the decrease in persistence rates.

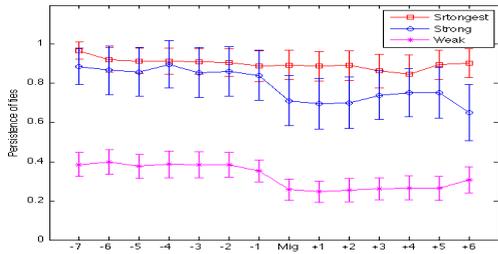


Figure 8. Persistence of ties at different tie strengths.

In addition to the three groups of social ties, Fig. 9 shows the persistence rates of different values of tie strength. Likewise, the tie strengths of greater than 3.0 appear to be independent of migration while other tie strength levels' persistence rates are impacted by the migration.

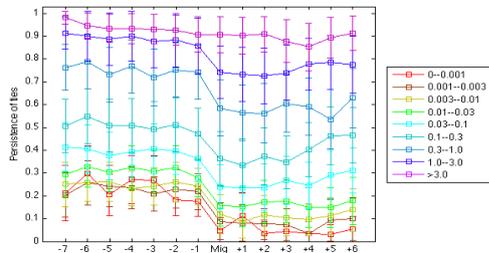


Figure 9. Persistence rates of different values of tie strength.

So, for those ties that can be impacted by the migration (strength of less than 3.0), the question is “Can we estimate the persistence rate after migration if we know tie strength and migration distance?” In other words, how likely an arbitrary tie would persist after migration takes place given its tie strength and migration distance. We need to derive the post-migration persistence rate as a function of social strength and distance of migration. Let Φ_{pre} , Φ_{post} , and $\Delta\Phi$ denote the persistence rate before migration, after migration, and persistence drop due to migration, respectively. Thus, we can express their relationships as:

$$\Phi_{post} = \Phi_{pre} - \Delta\Phi, \quad (4)$$

where Φ_{pre} can be expressed as a function of social strength and $\Delta\Phi$ can also be written in terms of migration distance.

We plot the of the average values of persistence rates of different tie strengths before migration (seen in Fig. 9) and find that the persistence rates (Φ_{pre}) and tie strengths (s) before migration have a linear relationship in log scales. As shown in Fig. 10, the fitting curve can be expressed as $\Phi_{pre} = (s/10)^{1/5}$.

Likewise, we also find that the drop in persistence of ties ($\Delta\Phi$) has a linear relationship with the migration distance (d_m) as shown in Fig. 11 with the fitting curve defined as $\Delta\Phi = \frac{1}{10}(d_m/10)^{1/8}$.

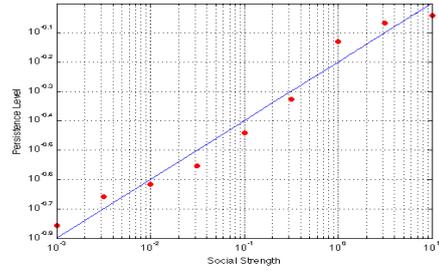


Figure 10. Average persistence rates of different social strength levels with its fitting curve on log scales.

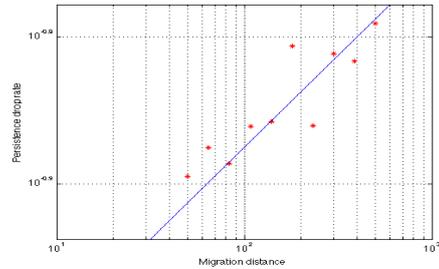


Figure 11. Average persistence drop rates of different migration distances with its fitting curve on log scales.

With these relationships, we can therefore derive the post-migration persistence rate as a function of social strength and distance of migration as follows:

$$\Phi_{post} = \left(\frac{s}{10}\right)^{1/5} - \frac{1}{10} \cdot \left(\frac{d_m}{10}\right)^{1/8}. \quad (5)$$

III. CONCLUSIONS

Pervasive technologies like the mobile phone, present an opportunity for researchers to study human behavior at a fine grain over a large scale [27]. In this study, we examine how migration influences social networks, and find that transitions in the strength of social ties are dependent upon their characteristics prior to migration. For example, the strongest ties predominantly remain the same, while strong and weak ties loose strength during the transition. The non-existent ties witness a modest change, with the majority emerging as weak ties.

In contrast, the transitions in social tie strength at the month-by- month level show significant transitional changes six months before migration and one month after migration. Furthermore, the results from the directional changes in social tie strengths (sociality levels), are consistent with these findings. Social inactivity is at its peak six months before and one month after migration. Moreover, the examination of the physical distance of ties reveals that, on average, people take approximately seven to eight months to build their new social circle in the new home locations after migration. Additionally, people tend to maintain relationships with their closest ties such as families and close friends regardless of any change in physical distance (migration). On the other hand, ties that are less resilient tend to be more dependent on the physical distance as demonstrated by the decrease in the persistence rates. In order to determine how likely

an arbitrary tie will persist after migration, we derive the persistence rate as a function of tie strength before migration and migration distance.

Our findings are consistent with a French study on moving home, where one of interviewees summarized her experiences:

“I think it’s when you are moving home it is also when you can distinguish who your true friends are, when moving and not when staying in the same city... because that is when we realize that among people who will eventually call you, even if you forgot to call them, who will call you, so if they call somewhere that it’s OK they want to keep in touch!” (Female, 30, Paris) (Mercier et al. [13], p. 128)

To our knowledge, this work is the first attempt to study the dynamics of social networks during migration using large mobile phone datasets. This initial study hopes to pave the way for more research into the dynamics of social networks during irregular occurrences such as migration, emergency relief, and special social events. The next step in this research will look to investigate different aspects of social networks during migration such as differences in tie strength, transitional changes between migrated people and non-migrated people, rates of disappearance of ties after migration, and tie evolution models.

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