Spatiotemporal analysis on imbalance of mobile phone network

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1. Introduction

The aggregated mobile phone data (the total amount calling numbers aggregated at the Base Transceiver Station (BTS) level), which are seen as the outcome of mobility pattern and calling behaviour, have been extensively studied to reveal the land scape of a city (Ratti et al. 2006; Pulselli et al., 2006; Jacobs-Crisioni and Koomen, 2012; Loibl and Peters-Anders, 2012). However, the mobile phone network is a directed network. The communication between BTS may form imbalance (In this paper it is defined as the difference between incoming and outgoing calls from one BTS tower to another. For example, if a BTS has more outgoing calls than incoming calls, it generates surplus, conversely, deficit) due to the heterogeneity of a city, which is caused by the difference of the mobility and calling pattern of residents in terms of time and space. Therefore, the imbalance of mobile communication network can be served as another indicator to describe the landscape of a city in terms of spatiotemporal heterogeneity. So that we can answer the questions like “if a city is more heterogeneous, should the mobile phone communication demonstrates more unbalance” or “do different land use types generate different unbalance patterns” via studying the deficit and surplus of mobile phone data.

Although research on the mobile phone data has been implemented to describe space-time structure of residents’ activities (Sevtsuk and Ratti, 2010; Sun et al. 2011), estimate population (Vieira et al. 2010; Manfredini et al., 2011; Rubioa et al., 2013), identify specific social groups (Vaccari et al. 2009) and detect social events (Traag et al. 2011; Laura et al. 2012). However, few studies could reveal the characteristics of imbalance in a city. This paper will first construct several indices for describing the imbalance of a mobile communication network and then systematically analyse its imbalance in terms of time and space based on the aggregated mobile data of an anonymous city.

2. Indices for measuring imbalance and reciprocity

The imbalance of a node in a network is referred to as the difference between inflow and outflow. We defined three indices regarding the mobile phone network. The first is the global index for measuring the imbalance of a network:

$$B(t) = \sum_i^N \left| \sum_{j=1}^{n_i} (out_{i,j,\Delta t}(t) - in_{i,j,\Delta t}(t)) \right| \quad (1)$$

where $out_{i,j,\Delta t}(t)$ is the number of calls from tower i to tower j between t and $t + \Delta t$, $in_{i,j,\Delta t}(t)$ is the number of calls from tower j to i between t and $t + \Delta t$, n_i is the number of links from node i. N is the number of nodes (i.e. BTS) in the network. If $\mathrm{B}(\mathrm{t})$ is high, the network is more unbalanced; otherwise, less unbalanced. The second is to measure the hourly relative surplus and deficit of the whole area (or a certain census unit L):

$$B_{n,L}(\mathrm{t}) = \frac{\sum_{i}^{N_L}\sum_{j=1}^{n_i}(out_{i,j,\Delta t}(t) - in_{i,j,\Delta t}(t))}{\sum_{i,j} out_{i,j,\Delta t}(t)} \quad (2)$$

where N_L is the number of nodes (i.e. BTS) in L. $B_{n,L}(\mathrm{t})$ is surplus if it is positive; otherwise, deficit.

The third index is to measure the hourly relative reciprocity of L:

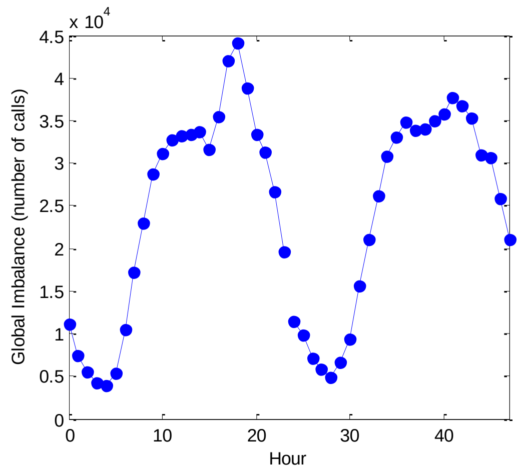
$$R_{n,L}(\mathrm{t}) = \frac{\sum_{i}^{N_L}\left|\sum_{j=1}^{n_i}(out_{i,j,\Delta t}(t) - in_{i,j,\Delta t}(t))\right|}{\sum_{i,j} out_{i,j,\Delta t}(t)} \quad (3)$$

3. Mobile phone data

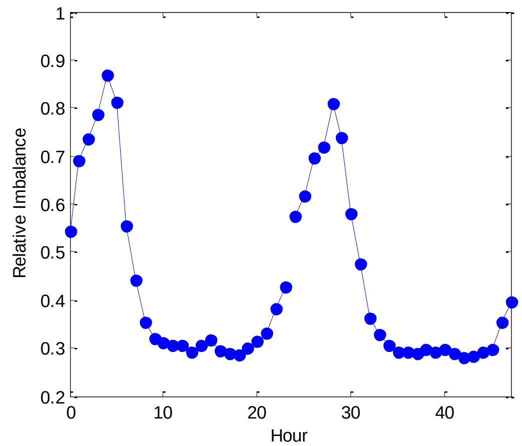
The mobile phone data we used in this paper are the hourly aggregated calling number at BTS tower level in an anonymous city. The number of BTS towers in the city is 5662. To study the unbalance of the mobile phone network, we collected the data in 30th March (Wednesday) and 2nd April (Saturday). In order to describe the imbalance generated at different land use types, we also collect the urban plan map of the city and combine the land use types to form the ultimate map. Here we divided the city into 5 land use types: Residential, Business, Commercial, Open space and Others (including school, hospital, government office and civic and community institution).

4. Temporal pattern

We then analysed the temporal characteristics of global imbalance for both workday and weekend. The hourly global imbalance ($B(t)$) and the relative reciprocity ($R_{n,L}(\mathrm{t})$) are displayed in Figure 1, each of which contains 48 points representing different hours in the workday and the weekend. Figure 1a shows that the maximum of index $B(t)$ is found at 6pm both for the workday and the weekend, at which $R_{n,L}(\mathrm{t})$ reaches it minima. Unlike $B(\mathrm{t})$, $R_{n,L}(\mathrm{t})$ reaches its maximum at 4am both for the workday and the weekend (Figure 1b), at which the minimum values of $B(t)$ are found. The reason is phone calls initiated at very early morning are very few. It is common to see there are only a few calls from one BTS tower to another in one hour but without calling back, so it is not difficult to understand the imbalance. As to the phenomena at 6pm, the reason is because the larger number of calls are initiated at that time, the minimum of $R_{n,L}(\mathrm{t})$, generated by dividing the large number, is obtained.



(a)



(b)

Figure 1. Hourly imbalance of calls

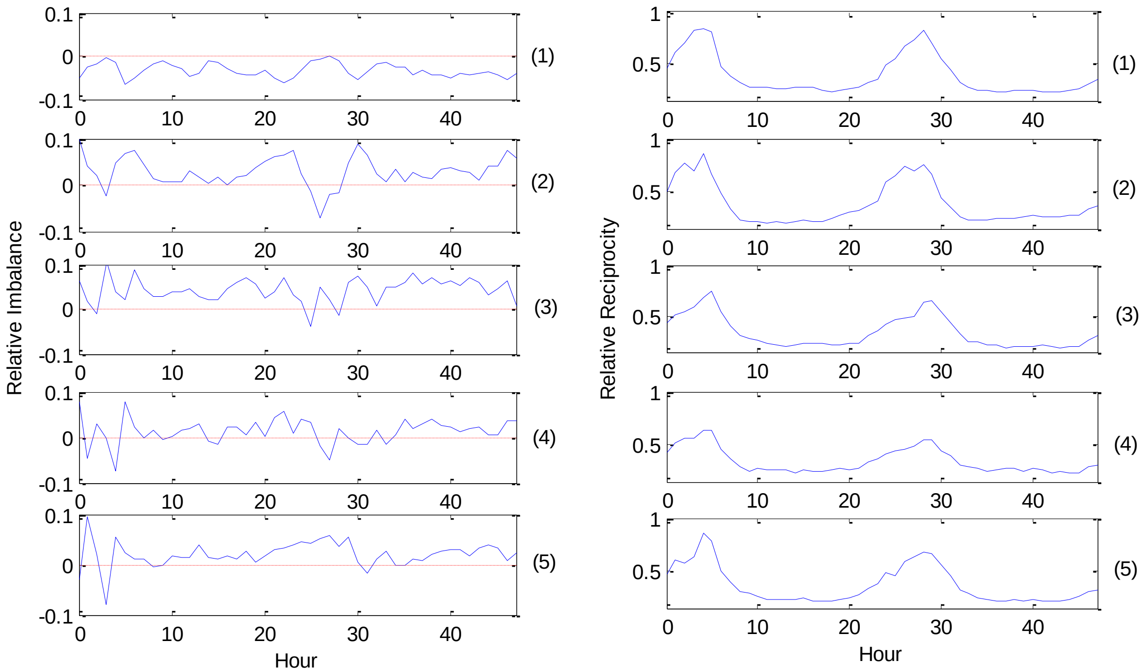
(a) Hourly global imbalance (B(t)); (b) Hourly relative reciprocity ($R_{n,L}$(t))

5. Imbalance over different land use types

To determine the difference of imbalance between various land use types, we calculate the indices for different land use types. Figure 2a shows the relative imbalance (Formula 2) while Figure 2b shows the relative reciprocity (Formula 3). We can see that different land use types demonstrate different patterns.

Figure 2a displays that deficit dominates the “Residential” area in the most of time, which indicates more incoming calls. The surplus dominates in “Business” and “Commercial” areas except for some time in the early mornings, which indicates more outgoing calls in workplaces. The surplus and deficit fluctuate around basic line for “Open Space”. Nevertheless, all of the imbalance level is very low, less than 10%. Comparing to “Business”, “Commercial” shows stronger imbalance in the daytime.

From Figure 2b, we find that the early morning demonstrates stronger relative reciprocity for different land use types, which is similar to the phenomena of whole area (Figure 1b). The “Residential” area has the strongest reciprocity in the workday. The “Other” area has the weakest daytime reciprocity while the “Open space” shows the weakest night reciprocity.



(a) (b)

Figure 2. Imbalance over different land use types
(a) Hourly relative imbalance; (b) Hourly relative reciprocity
(1-Residential; 2-Business; 3-Commercial; 4-Open space; 5-Others)

6. Spatiotemporal pattern of deficit and surplus

Figure 3 displays the trajectories of the centres of outgoing and incoming calls of the whole city and those of surplus and deficit both for the workday and the weekend. We find that the trajectories of outgoing and incoming calls show the similar pattern with some distances departed both in the workday and the weekend (Figure 3a and 3b). Specifically, the centres of outgoing calling are located to the east of those of incoming calls. In Figure 3c and 3d, the trajectories of deficit and those of surplus show totally different patterns both for the workday and the weekend. The trajectories of deficit are located at the northeast while those of surplus are located at the southwest. These figures indicate that more calls are initiated from the west and more calls are received at the east.

In the workday, the centers of outgoing calls and incoming calls move to the south at the mid of the day, which is coincidence to the fact that the business center in the city is also located in the south end. In the weekend, the centers of outgoing and incoming calls move to the place nearby the center of the network at the mid of the day. The reason for the difference between the workday and the weekend could be in that in the workday more people move to the south (commercial area) and initiate/receive more calls.

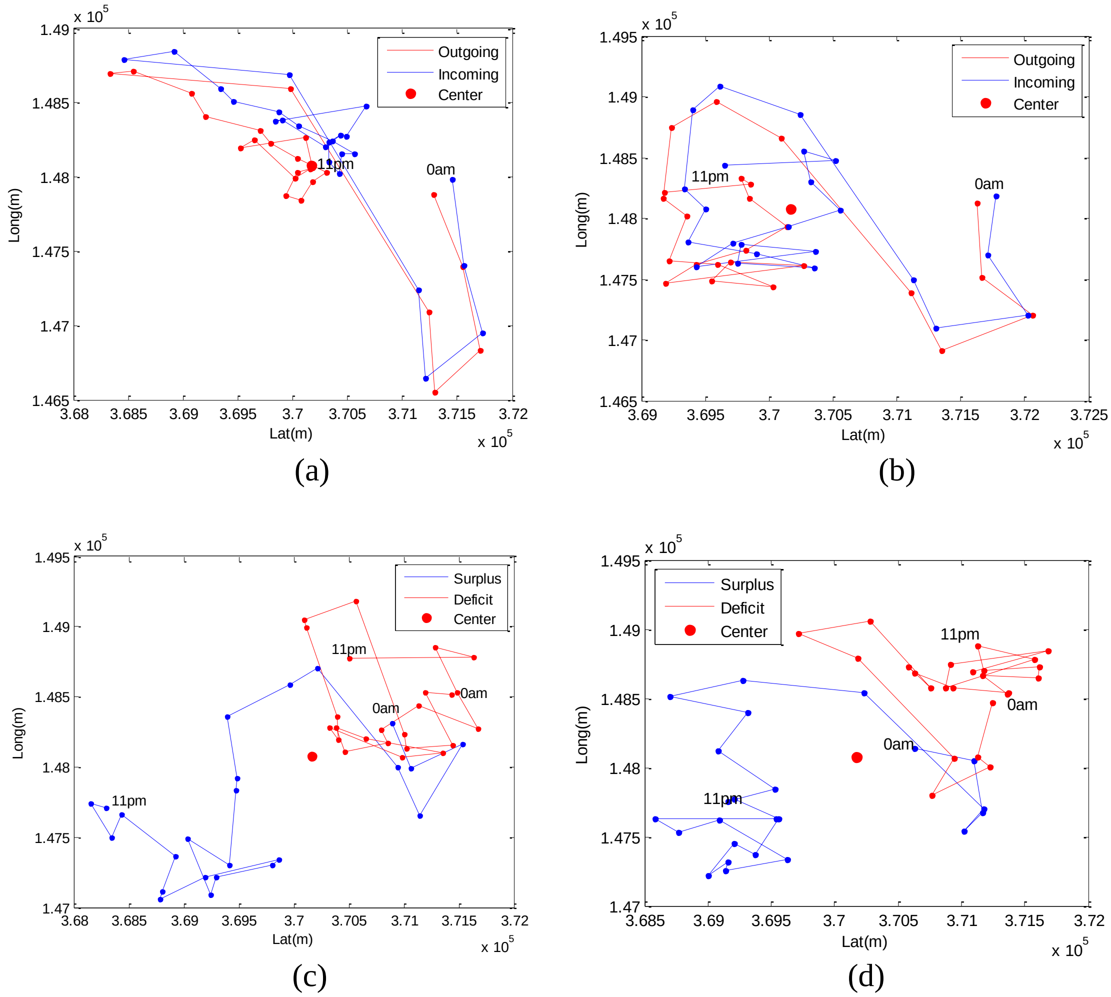


Figure 3. Trajectories of calls and imbalance

(a) Trajectories of outgoing and incoming calls for the workday; (b) Trajectories of outgoing and incoming calls for the weekend; (c) Trajectories of surplus and deficit for the workday; (d) Trajectories of surplus and deficit for the weekend. (Note that all trajectories begin at 0am and end at 11pm)

7. Conclusion

This paper systematically analyses the spatiotemporal imbalance of mobile phone network. Regarding the temporal pattern, we find that: the maxima of the global imbalance are located in 6pm while the maxima of the relative imbalance are found in the early morning (around 4am) both for the workday and the weekend. Regarding the spatial imbalance over different land use types, we uncover that: (1) the “Residential” area is dominated by the deficit both in the workday and the weekend; (2) the “Commercial” area shows the highest imbalance. The spatiotemporal pattern tell us that: (1) more calls are initiated from the southwest and received in the northeast, and (2) the centers of outgoing calls and incoming calls moving to the south at the mid of the day can be explained by the fact that the commercial center is located at the south.

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