Chapter 2
Mobile Phone Data to Describe Urban Practices: An Overview in the Literature

Abstract This chapter focuses on the potentialities offered by mobile phone data in reading the site practices and rhythms of usage of the contemporary city, providing a research framework of the most promising approaches. Research approaches using ICT and aggregated cellular network log files to identify fine-grained variations in urban movements are presented to argue how mobile phone data can be treated as a useful source of information on the real use of cities. Because of the pervasiveness guaranteed by the ubiquity of mobile phone networks, this chapter shows how these datasets can overcome limitations in the detection of latency, typical of traditional data sources, while also providing valuable information on temporary urban populations. Referring to the outcomes of research on passive and anonymous monitoring of cell phone traffic (i.e. Social Positioning Method, Mobile Landscape and Real Time Monitoring, Automated Land Use Identification), we illustrate the potential and the challenges of these data source in complementing more traditional survey methods.

Keywords Mobile phone data · Tracking technologies · ICT · Mobile landscapes · Social Positioning Method

Research into the use of mobile phone data and ICT has for some years been showing the great potential of these data in reading fine-grained variations in urban movements over time and estimating human movements through urban spaces (Ahas and Mark 2005; Ratti et al. 2006; Kwan et al. 2007; Reades et al. 2007).

ICT and the passive and anonymous monitoring of cell phone traffic provide information that traditional data sources for urban studies (census data, surveys and interviews or the deployment of sensor networks) are unable to produce, because they consider the users generating telephone traffic as "sensors of a network".

In doing so, with these data we can, at the same time, overcome the limitations in detection of latency typical of traditional data sources and exploit the pervasiveness guaranteed by the ubiquity of mobile phone networks, as well as offering a "longitudinal perspective" on the variability in human travel activities (Jarv et al. 2014), validly complementing traditional methods.

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If we consider the observed individual traces and aggregated mobile phone traffic as the result of individual behaviours and habits, mobile phone data can be treated as a useful source of information on the *real* use of cities. These data capture traces of temporary populations and densities in the use of urban spaces (Ahas et al. 2010a, b), difficult to intercept using traditional data sources. These temporary practices have an increasing quantitative and qualitative effect on urban spaces, services and transport supply. Human presence and its variability over time is an index of urban vitality and liveability over time (temporal extension of urban activities), although there is not necessarily reference to functional patterns. This confirms the importance of ICT and mobile phone data in urban analyses (Becker et al. 2011) and in its contribution to the classification of urban spaces according to their users' practices and behaviour (Reades et al. 2007; Soto and Frías-Martínez 2011a, b).

Considering the experiments undertaken as reported in the literature, there are basically three main types of survey methodology (Manfredini et al. 2012) (Fig. 2.1):

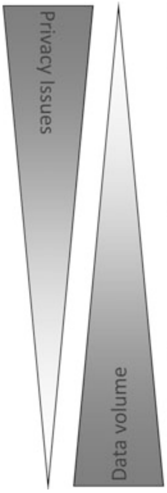
- Individual traces detected with tracking technologies of a sample, useful to study the mobility behaviour of specific groups of people;
- Individual trajectories, previously anonymized and collected by mobile phone carriers, useful to study geometric patterns of individual mobility, without geographical references (Network science);
- Mapping geo-referenced and aggregated mobile phone data of utility in studying land use density (Mobile landscapes); network measurement results related to active calls allow for tracking of all active handsets.

The first technique—individual traces of a selected sample—offers a more precise result because it is possible to record the origin and destination track of individual moves. On the other hand this means a greater cost for data processing and the necessity to build up a statistical sample of users. Moreover, problems related to individual privacy raised several ethical questions for this type of research. This technique is based on active mobile positioning (tracing) that is performed on specific location request, both as network based positioning and as handset positioning method.

By contrast, with the use of aggregated data collected from the network (mainly cell towers), it is possible to shift the focus from the individual level, directing interest on the emergence of complex urban dynamics related to the places that people use and frequent (Song et al. 2010; Gonzalez et al. 2008).

With the third technique, the focus becomes the use of urban space by the people, considered as time and space dependent variable. The scale of investigation of this type of synthetic data allows for representation of urban density also through mapping in real time (called soft real-time because the data are usually returned with a 15-minute lag).

Unlike origin-destination matrices or individual mobile phone tracking, aggregate data do not indicate where a caller comes from or goes to, but simply estimate the amount of call volume in a given network cell at a given time. Although we lose the traces of the origins and destinations of individual movements, this limitation does not appear relevant if, by using the volume of cell activity in mobile network



Data	Research area	Purpose
Tracks of displacements of individuals of a small selected sample (case study)	Tracking technologies (GPS, SMS, ...)	Study of mobility behaviour of specific group/population category
Tracks of calls of individual phone users (active mobile positioning)	Network science	Study of geometrical patterns of the mobility of individuals (deprived of the specific geographical reference)
Spatial distribution of cell phone activity (derived from cellular network log files)	Mobile landscapes	Study of the density of use of a territory

Fig. 2.1 The research fields on active and passive mobile positioning

cells, we can estimate the distribution patterns of the population in the different time slots considered for the survey (hourly, weekly, seasonal).

From a technical point of view, the third technique (spatial distribution of the cell phone activity) is based on analysis of aggregated data and traffic volume detected on network towers. Among the methods proposed in the literature, we may mention the social positioning method (SPM) of Positium LBS (Ahas and Mark 2005; Ahas et al. 2010a, b) based on active and passive positioning systems, and mobile census (MIT Senseable City Lab) which is instead a totally passive tracking system.

The opportunities offered by the use of mobile phone data compared to traditional data sources are:

- A more regular distribution of data in time and space;
- A finer network of detection;
- The precision of information (the accuracy of locational data, the frequency of data availability);
- The time required for calculating the position;
- The availability of service coverage, especially in urban areas;
- The characteristics of aggregated and anonymous data do not infringe on the privacy of mobile phone users;
- The implementation of integrated solutions that enhance the information obtained from mobile data, combining information from the identification code of the telephone prefixes for outgoing and incoming calls (ID of incoming and outgoing calls), but also on user profiles (social identification).

Conceived within the stream of studies on the use of ICT and mobile data, this project sought to verify whether mobile traffic data could be used to describe the rhythms of the city and its spatial differences in terms of the density of practices.

The aim of our project is to understand patterns of daily life in the city, using three types of mobile phone data (Erlang measures as telecommunication traffic intensity, O/D matrix as aggregated tracks of mobile phone users and MSC as Mobile Switching Center) and to illustrate people's movements and the multi-sited nature of the daily-urban activities.

2.1 About Mobile Phone Data

Since locational data (GPS, A-GPS, SMS) are becoming increasingly available and their applications are currently a hot topic in the mobile phone industry, aggregated locational data have not yet been widely used to describe urban systems.

Research projects on this topic are emerging in particular on the mapping of the mobile phone activity in cities or on the visualization of urban metabolism[1] based on handset movements.

Using mobile phone traffic as a means for monitoring urban practices shows that phone calls are closely related to population density in urban areas: the intensity of activity in a cell (the area covered around an antenna) is proportional to the presence of mobile phone users (Sevtsuk and Ratti 2010; Reades et al. 2007; Ratti et al. 2006; Ahas and Mark 2005).

Most of the researches focus on the Erlang data,[2] using the volume of call activity in mobile network cells as the spatial unit of analysis, in order to describe the correlation between mobile phone data and people's daily activities (Ratti et al. 2006; Sevtsuk and Ratti 2010).

Graphic representations of the intensity of urban activities and their evolution through space and time, based on the geographical mapping of mobile phone usage at different times of the day, are the main output of the Mobile Landscape approach (Ratti et al. 2006).

The main question is how to correlate the Erlang trends—a measure of the density of phone activities—with the density of people.

Because the data can be used to map different urban domains and their occupants, some studies focused on integrating available mobile phone data with traditional data sources and surveys (Witlox 2007; Manfredini et al. 2012).

[1] About the definition of urban metabolism: Wolman (1965); Brunner (2007).

[2] Erlang data are the average number of concurrent contacts in a time unit. The Erlang data provided by Telecom Italia describe the density of mobile phone traffic every 15 minutes across areas measuring 250 × 250 meters.

In this direction, statistical models supported by empirical data (traditional sources or surveys) are proposed to investigate:

- the relationships between location coordinates of mobile phones and the social identification of the people carrying them as Social Positioning Method and its possible applications in the organization and planning of public life proposed by Ahas and Mark (2005);
- the relationships between mobile phone measures (the volume of call activity in mobile network cells as Erlang) and population distribution in cities (Sevtsuk and Ratti 2010);
- the classification of urban spaces, according to mobile phone uses (Reades et al. 2007; Soto and Frías-Martínez 2011a, b), in which different "basic" profiles of city usages can concur to identify different profiles of use and consumption.

Another important perspective concerns the use of mobile phone data as traffic monitoring tools (Caceres et al. 2008; Qiu and Cheng 2007; Fontaine and Smith 2005). In terms of volume data, the concept of using mobile phone data as probes has been explored by various researchers working on simulated frameworks (Fontaine and Smith 2005), as well as in field tests (Bekhor et al. 2008; Höpfner et al. 2007; Thiessenhusen et al. 2003).

In all these cases, traffic volume data is associated with cell phone transit through a boundary area using processes related to mobility management, detecting boundary crossing rates either at inter-cell boundary level (handover) or at location area boundary level (LU procedure).

Most of these studies focus on the handover[3] event detecting phone transit through boundaries between two cells. However, these studies concluded that accurate vehicle flows could not be obtained directly from mobile phone data due to the characteristics of this data source.

The main question is how to correlate the number of phones crossing with the real number of vehicles crossing. Volume data on inter-cell boundaries provided by mobile phones does not yield information on the complete set of vehicles crossing a boundary, but only a statistical sample of all travelling vehicles.

According to these findings, more accurate estimates for the number of vehicles can be obtained by means of appropriate processing to relate both measures (phone counts and vehicle counts) (Caceres et al. 2012).

Although studies in this area show promising results, the attempt to establish a "direct" link between phone calls and the number of people or trips comes up against some major limitations.

[3] Handover refers to the process of transferring an ongoing call or data session from one antenna to another. It, therefore, provides information on the movement of mobile phone users through the network.

To begin with, the use of the mobile phone depends on age, gender, profession, time and activities (Aguiléra et al. 2009), and it is difficult to take into account the possible cross effects: there are so many different situations that it is almost impossible to reach a conclusion on a purely quantitative basis derived solely from the mobile phone data.

This is particularly important if we want to use mobile phone data for urban investigations with the aim of planning the provision of personal services, for which statistical data are needed.

Next, long term effects may diverge from short term effects, in particular because when individuals acquire familiarity with these technologies, they may start to combine them, or because the equipment rate increases and the available applications change rapidly, as has been the case with mobile phones. Moreover, the correct measurement scale is not necessarily that of the individual.

2.2 The Social Positioning Method and Its Possible Applications

Social Positioning Method by Ahas and Mark (2005) studies social flows in time and space by analysing the location of mobile phones and the social identification of people carrying them. Mobile positioning data use different sources: "active mobile position (tracing) data collected after a special query/request to determine the location of a mobile phone" and "passive mobile positioning data collected from secondary sources such as the memory or log files of mobile operators" (Ahas et al. 2010a, p. 46). In doing so, Social Positioning Method uses location coordinates of mobile phones and social identification of the people carrying them for purpose of studying space-time behaviour and commuters' space-time movements. Therefore, this mobile survey saves a lot of time and resources compared to traditional data collection such as paper survey, questionnaires, and it supplies not only location information, but also the characteristics of the phone users. SPM offers more precise information than can be obtained from travel diaries and questionnaires according to the large number of people that can be estimated and the temporal accuracy to observe time changes in urban space use. Compared with tracking data (GPS, mobile drive, travel diaries…) mobile positioning data have some advantages (Ahas et al. 2010a, p. 53):

- Mobile phones are widespread and popular in developed and developing countries;
- People like to carry mobile phone with them, and they recharge the battery carefully;
- Data are originally digital, free from respondents' memory bias or manual digitalisation errors;
- It is possible to ask respondents extra questions or location-aware questions during a study, using text messages or special environments.

The high quality of positioning data today gives an overview of people's actual locations, as well as the possibility to describe the space-time movement of different social profiles of the users, because mobile data findings are correlated with the characteristics of the mobile phone users (Ahas and Mark 2005). Some conditions make this approach particularly promising also for urban planning, "making planning more human-centered" (Pulselli and Ratti 2005)—as is the case in some Estonian cities,[4] for instance: the SPM data collection system is quite simple[5] and the widespread use of mobile communication, also in poorer countries with wireless networks, is cheaper and easier to construct than wired networks.

In addition to these aspects, there is also a dimension related to the role of the mobile phone in daily living practices: the mobile phone is no longer just a phone, but rather a multifunctional media device with library, mail, which makes it an inseparable part of the contemporary daily lifestyle.

According to Elliot and Urry (2010), mobile phones, like the other technological devices (laptop computers, wireless connections) "enter into the constitution of self and of other novel social patterns" (Elliot and Urry 2010, p. 30) becoming "miniaturized mobilities" that "afford a fundamental liberation from place" (Wellman 2001, p. 238). These "miniaturized mobilities" are part and parcel of a continuous coordination of communications, social networks and the mobile self.

In this way, as suggest by Ahas and Mark (2005), Social Positioning will provide maps with survey of real time data of who is moving, where and how. It will become possible to visualize the social composition of streets and individual premises, to provide data about total numbers of people and their movements. This could also highlight crisis situations such as traffic jams and accidents, and would help to manage problems arising from the movement of people.

In this perspective, Ahas et al. (2010b) developed the "anchor point" model to locate and distinguish an individuals' daily anchor points (i.e. home and work) based on call activities.

The above applications have been the subject of experimentation by the Positium LBS (Location Based Services), one of the first companies to have commercialized the use of mobile data applications for marketing and management planning. Founded in 2001 as an interdisciplinary spin-off of the University of Tartu and supported by the Estonian mobile operators which provide a rich database of user data, Positium LBS has managed, over the years, to promote research of great scientific importance. Among the most important tools supplied by Positium LBS there are tools for geographic analysis of the movement of people and tools serving for observation of tourist flows (for example, the Position Touring Barometer, which is a web-based system that analyses the reports drawn up by tourists).

[4] In Estonia mobile data have been used since 2008 for calculation of the balance of payment travel item of the national central bank (Position LBS 2014).

[5] Persons carrying the mobile phone (possibly anonymous), space coordinates x and y, the third height dimension (will be added in a near feature), and finally time coordinates z.

2.3 Mobile Phone Measures and Population Distribution in Cities

The early research works in the field of mobile phone data include those by MIT SenseableLab,[6] thanks to unprecedented access to aggregate mobile phone data. The products of the research have high innovative value and, at the same time, offer several ways to start the transfer of technology for possible commercial applications.

The researches of the laboratory are mainly based on the use of three types of aggregate data provided by the mobile network: cell phone traffic intensity, traffic migration (handovers) and traces of registered users as they move through the city (Ratti et al. 2006).

The data are used to derive real-time pictures of the flow of people in the urban environment (i.e. Mobile Scape Graz 2005; Real Time Rome 2006; Wiki City Rome 2007) and views of the traffic flow of mobile phone and IP traffic together (i.e. New York City Talk Exchange 2008).

The maps are not only useful visualizations of the movements of people on a cartographic support, but are also suitable as tools for analysis of the variability in time and space of the demand for services that people can generate. In particular, in Real Time Rome (2006), the analysis of pedestrian movements of people, in cross comparison with the supply of public transport, verifies the adequacy of the public transport supply at the urban level.

Depending on the quality and richness of the available information, we can get different results. If in the early works in collaboration with Telecom Italia,[7] the data provided were related to the intensity of traffic (Erlang and handovers data), in projects in partnership with AT&T,[8] the data provided were enriched with the identification code of the telephone area for outgoing and incoming calls (ID of incoming and outgoing calls).

This type of information has revealed the degree of connectivity of a specific place with the rest of the world, expanding and providing analytical elements useful in the study of urban sociology in the globalization processes (Castells 1996; Sassen 2007).

Starting from the research of Senseable City Lab, there are many application tests. Among these are:

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[6] Senseable City Lab is a laboratory at the Massachusetts Institute of Technology, supervised by Carlo Ratti, which took the form of a consortium to collaborate with private and public partners. http://senseable.mit.edu.

[7] Telecom Italia is the leading Italian telecommunications company, supplying Italian and international fixed telephone services, mobile phone services, Internet and cable television.

[8] AT&T Inc. is a phone company based in San Antonio, Texas with head office in the USA.

- Reality Mining MIT MediaLab[9] identifies the collection of environmental data detected by digital tools in order to study the social behaviour of people. In particular, mobile phone data analysis allows for study of the practices of social networking in order to model the people's behaviour through stochastic methods. The laboratory was engaged in a meticulous survey of mobile phone data of 100 people between 2004 and 2005. With collection of more than 350,000 h of recorded data it has been possible to establish a database with information about the evolution of social networks over time, about the ways of living of the people and about the relationship between social networks and proximity;
- Current City[10] applies some of the techniques developed at Senseable City Lab on the methods of data collection to offer services to public and private institutions interested in understanding the spatialization of mobility patterns. The main applications are reporting and management of the emergencies, and the management of urban mobility. The strength of Current City lies in effective modes of representation and communication of data flows through maps in real time.

2.4 The Classification of Urban Spaces According to Mobile Phone Uses

The classification of urban spaces according to their actual use by people is an interesting application of recent georeferenced data and in particular of data derived by mobile phone networks, potentially useful for planners as a tool of investigation of the actual use of the contemporary city, otherwise often unavailable.

Works in this direction are based on the idea that people's behaviour can be a good indicator of the effective urban zoning.

Based on the available data the strategy is often to classify different kinds of people's behaviour (generally this is done considering similarities among different time-series), often called signatures. The signatures are then analysed and clustered. The characterization of places in terms of signatures and consequently the attribution of a place to a certain cluster, leads the definition of the zoning, i.e. the division of the city into areas, sharing some behavioural characteristic.

We can distinguish two different kind of approaches: the first is based on distinct traces of users, the second on aggregated data directly attributed to places.

The first approach characterizes for example the work of Becker et al. (2011), the main focus being on users and their behaviour. A classification of the land is subsequent to the classification of users based on the call detail record data (voice and SMS) of 2 months. The authors try to answer several questions on city dynamics. Firstly they identify what they call the "laboursheds", that is the

[9] http://reality.media.mit.edu by Nathan Eagle.

[10] http://currentcity.org by Euro Beinat, Assaf Biderman, Francesco Calabrese, Filippo Dal Fiore, Carlo Ratti, Andrea Vaccari.

residential areas which contribute workers to Morristown. The analysis is conducted following the traces of those users with frequent mobile phone activity in Morristown during working days. They then use the ZIP code of the billing information associated with the SIM to infer the residence of the users. They compare their results with the census, finding significant similarities. Similarly they study the "partyshed", or the zones of provenience of late night revelers, this time starting with those users captured downtown, the area known for its leisure function. Once again the "shed" is identified by the ZIP codes. Lastly the work proposes a clustering analysis of mobile phone usage patterns in order to characterize people (e.g. "heavy voice users who have heaviest usage during business hours, are a bit less active on the weekend, and have little to no SMS usage"). Seven clusters are analysed (k-means clustering) and the geographical "footprint" of the users of each cluster are considered. The identification of home-work location is a task performed with similar data also in other studies. Similar to this work are those of (Ahas et al. 2010a, b; Bekhor et al. 2011), where the focus is on users' behaviour and in particular on the possibility of finding their home locations from cellular phone traces. Different data sets are analysed and the results compared with census data finding good correlations.

Recently also other different data sources reporting information on people traces have been exploited to infer urban zoning.

The work presented in Yuan et al. (2012) is more properly devoted to the identification of different functions in the city. The study analyses several months of taxi GPS traces, but the same authors suggest the possibility to use mobile phone traces within their analysis framework, and a dataset of points of interest (POIs) in Beijing. The idea is that the only presence of certain types of POIs (e.g. restaurants) cannot determine the kind of function of an urban area, but that the mixed exploitation of POIs and mobility information can help the identification of the land use.

The same kind of data is considered in Qi et al. (2011) where the authors exploit the temporal variation of the geolocalized amount of getting on-off of taxis (from GPS traces) to infer the social function of city regions. "regions with different social function have their distinctive temporal variation patterns". They identify three categories of region: train stations, entertainment districts and scenic spots (tourists) and label a set of training samples (zones). They then perform an agglomerative cluster analysis on the whole set and label the clusters by a majority vote of its training samples.

Coming to the second approach exploiting data directly related to places, we can start with one of the first works on this topic, the well-known article by Reades et al. (2007) where, analyzing cellular network data of Rome, a k-means clustering of a simplified kind of Erlang signature is conducted, arriving at an interesting classification of the city in 5 type of areas, two of which (night time leisure and commuters) are particularly consistent with the actual knowledge of the city. The authors suggest that more sophisticated techniques could ameliorate analyses of this kind. Such is the case of (Sevtsuk 2008), where the author classifies places in Rome by means of their Erlang signatures and explains the population distribution trends through socio-economic characteristics of the areas. More specifically, Sevtsuk clusters the three first eigenvectors (of a Principal Component Analysis) of the Erlang signature of the cellular network cells arriving at a subdivision in 16 clusters. He then analyses the three largest clusters, resulting in a concentric structuring of the city, starting from the peripheral zones and arriving in the city core. Comparing these clusters with socio-economic data the author finds a strong correlation "between areas that resemble in network usage and areas that resemble in demographic and business composition".

In Horanont and Shibasaki (2009) the authors, besides the presentation of their web-based visualizations of population density predictions based on Erlang data in Bangkok, describe a methodology for land use classification based on Erlang time series. After having chosen four points of known different land use (residence, business, shopping, university) they calculate the respective Erlang signature of these zones (like other authors they consider the mean hourly aggregation), discussing how these can be considered representative of the kind of usage of similar zones.

Telefonica Research, the research and development company of the Spanish telecommunication group Telefonica, started its work on the topic with the seminal work by Froehlichet et al. (2009), which analyses data of usage of bike sharing stations in Barcelona. The authors apply dendrogram clustering (Duda et al. 2000) identifying different clusters of station usage. Besides the direct application of their methodology to predict future bike station usage behaviour, they insightfully suggest how shared temporal trends in station usage can allow to infer attributes about neighborhoods (e.g., residential versus commercial, proximity to downtown). After this work, Telefonica research proposed other works based on cellular network data. In Soto and Frías-Martínez (2011a) the topic is urban zoning analysis by means of mobile phone usage intensity. The authors start with CDR records (1 month in 2009), aggregated in order to obtain an antenna level information, namely the measure of the number of calls in the unit time for the cellular network antennas. A representative time series (of the average values of the single week days in one case, of the mean working day followed by the mean weekend day) of the week is considered the "signature" of the antenna. The authors derive from these signatures, by means of an unsupervised clustering technique—k-means clustering with Euclidean and Dynamic Time Warping distance measures—five clusters that they associate with five main land uses in Madrid: residential areas, office areas, nightlife areas, weekend leisure areas, hybrid land use. They discuss the spatial characterization of these clusters reporting that the results are in accordance with their expert knowledge of the city. They finally use the knowledge extracted from the case of Madrid (the cluster representatives) within a classifier which they experiment to automatically classify the land use in Barcelona. Finally in Soto and Frías-Martínez (2011b) the same authors outline the fact that city areas are generally not characterized by just one specific use, especially in older cities like Madrid, on which they conduct their analysis, and for this reason they introduce the use of c-means, a fuzzy unsupervised clustering technique for land use classification, which shows for each area a certain degree of association with each class. In the same paper fuzziness is then abandoned to favour the identification of areas with a clearly defined use (with a degree of membership to a cluster over a certain threshold). They identify 5 clusters which they associate with five types of districts: industrial parks and offices, commercial and business areas, nightlife areas, leisure and transport hubs, residential areas. They validate the unsupervised classification thanks to their expert knowledge of the city.

We will discuss later, in Sect. 3.2, a different methodology for the classification of urban spaces by means of Erlang data, which, like the approach of (Soto and Frías-Martínez 2011b), takes into account the fact that a single zone can be characterized by different uses.

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