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Exploring cellular network handover information for urban mobility analysis

Merkebe Getachew Demissie *, Gonçalo Homem de Almeida Correia [1], Carlos Bento [2]

Coimbra University, Civil Engineering Department, Rua Luis Reis Santos, 3030-788 Coimbra, Portugal

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ABSTRACT

The progressive trend of urbanization involving changes in the activities of a city has created several problems. Addressing these problems requires reliable and detailed information regarding the urban structure and its dynamics. Previous studies have tried to explore cellular networks data for urban analysis, yet little attention has been given in exploring mobility related events of cellular networks. This study uses handover, which is the process of transferring an ongoing call from one cell to the other, to capture urban dynamics. The handover data was collected from cellular towers in Lisbon, Portugal. First, our method started with a pre-processing of the handover data. Then, experiments were carried out to understand the city dynamics through GIS visualization and statistical analysis. The visualizations provided a qualitative explanation of how the movement of calls is useful in highlighting the flow of people in urban infrastructures. Using statistical analysis, two important relationships were proved: there is a significant association between cell towers with a high number of incoming handovers and a high presence of people in their vicinity; and a greater proximity to the main road links of cell towers characterized by a high number of incoming as well as outgoing handovers thus towers denoting more movement. Our results suggest that the handover information, taking the advantage of its pervasiveness, can provide ways to analyze city dynamics at a larger scale. This approach complements the effort of traditional urban data collection methods, which are usually made available less frequently to urban planners and policy makers.

1. Introduction

1.1. Background

Urban areas have diverse activities and complex spatial structures that are supported by urban transport systems. Urban productivity is highly reliant on the competence of its transportation system to move passengers, and freights between multiple origins and destinations. The majority of urban transport problems occurred when the system failed to satisfy the mobility requirements that are generated by the various activities in the city. These problems include: heavily congested roads, parking difficulties, increased pollution, fragility of public transportation systems, and loss of space for productive activities (Rodrigue et al., 2006). To address these problems, transport and urban planners have to develop a means to understand people's mobility patterns. This requires reliable and detailed information regarding the flow of people in a city and understanding of activities at different places in a given city (Becker et al., 2011b). Analysis of activities at different places in an urban environment provides a perspective on human mobility and gives an opportunity to assess the spatial and temporal patterns and trends, which would help for better planning of city dynamics (Becker et al., 2011b).

Currently, planners learn about mobility patterns of people through different techniques, such as survey by interviewer or phone and vehicle counting. These methods have the advantage of providing detailed information about urban mobility patterns. Comprehensive commuting studies, however, require years to be completed and many metropolises learn the presence of new trends only after the release of new census results (Becker et al., 2011b; Ratti et al., 2006). One way that has been tried to obtain this kind of information is through the use of cellular networks.

The pervasive use of telecommunication technology has changed our ways of exchanging information, interactions among individuals, movements, and use of urban space (Pulselli et al., 2008). These interactions generate mobility related events in the cellular network, such as location area, route area, and cell updates (Valerio et al., 2009). These events are useful to sense the movement of large populations of people more regularly, with reduced cost and in a large scale (Becker et al., 2011b). As a consequence, cellular networks mobility related events become an important new

* Corresponding author. Tel.: +351 239 79 71 05.
E-mail addresses: demissie@dei.uc.pt (M.G. Demissie), gcorreia@dec.uc.pt (Gonçalo Homem de Almeida Correia), bento@dei.uc.pt (C. Bento).
[1] Tel.: +351 239 79 71 05.
[2] Tel.: +351 239 79 00 00.

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source of information for analysis of urban transportation and urban dynamics.

This study uses handover, which is the process of transferring an ongoing call from one cell to the other, to explore its usefulness for urban mobility analysis. Our analysis gives contributions to the following research questions of relevance to urban transport planners, transport geographers, and urban planners: How is it possible to highlight critical spots in the urban road network without incurring great costs? How do we understand the mobility patterns of people in a city? Is handover data adequate and available in the form required for urban analysis? How is the prospect of handover data to detect congestion?

Several authors have studied how cellular network data can be used for understanding people's movements and for urban planning purposes. The study by Asakura and Hato (2004) pointed out limitations associated with questionnaire type travel surveys such as person trip surveys and suggested tracking surveys that measure the precise space–time attributes of an object. Nobis and Lenz (2009) obtained a panel data from the years 2004 and 2007 to examine the complementarity between telecommunications and travel behavior at the level of individual persons. Calabrese et al. (2010) acquired nearly one million cellphone traces with the aim of associating these traces with social events. Results of the experiment showed there was a strong correlation in that: people who live close to an event were preferentially attracted by it; events of the same type show similar spatial distribution of origins. Sohn et al.(2006) collected Global System for Mobile communications (GSM) traces walking and driving events from everyday lives of three people for a month. The result showed that 85% of the time it was possible to correctly recognize mobility modes among walking, driving, and stationary. González et al.(2008) obtained trajectory of 100,000 anonymized mobile phone users whose position was tracked along 6 months to form statistical models of how individuals move. Results showed that human trajectories exhibit a high degree of temporal and spatial regularity. Järv et al. (2012) used call detail records (CDRs) of mobile phones to investigate how and to what extent suburbanite commuters affect the evening rush hour traffic. The result shows the daily workplace-to-home trip contributes only 31% of the total evening rush hour traffic.

The study by Pulselli et al. (2008) showed how information from cellphone usage can be used to represent the intensity of urban activities and their evolution through space and time. The studies by Ratti et al.(2005) and Calabrese et al.(2011) also developed city-scale analysis that showed a real-time representation of city dynamics through Erlang values, handover and cellphone trajectories from registered users. The study by Reades et al. (2007) also investigated the correlation between call volume and urban activities at six distinct locations in Rome. Handover extracted from anonymized CDRs were also applied to identify which routes people take in a city (Becker et al., 2011a). The study by Ahas et al. (2010) developed a model that illustrates how passive mobile positioning data can provide information about regularly visited places. A comparison of the model results with the population registered data showed the developed model described the geography of the population relatively well. Tranos et al. (2013) developed a city-scale digital accessibility indicator based on the installed digital infrastructure, and the opportunities and cost for virtual interactions was defined on a spatial basis. A traditional geographical notion such as physical distance proved to be able to reflect virtual interaction costs just like physical interactions.

1.2. Our approach

Previous studies have presented the use of cellular networks handover related data (double handover, cell dwell time, and CDRs) for traffic parameter estimation (Alger et al., 2005; Bar-Gera, 2007; Caceres et al., 2007; Herrera et al., 2010; Liu et al., 2008), OD estimation (Pan et al., 2006; White and Wells, 2002), analysis of urban dynamics (Becker et al., 2011b; Calabrese et al., 2010, 2011; Ratti et al., 2005), congestion detection (Hongsakham et al., 2008; Thajchayapong et al., 2006), and to understanding people's movements and for urban planning purposes (Ahas et al., 2010; Becker et al., 2011a; González et al., 2008; Järv et al., 2012). Even though many experts are convinced on the usefulness of cellular networks information for the analysis of urban mobility, some important limitations remain to be addressed. These limitations have different effects based on the type of urban problems under investigation:

a. *Limited accuracy*: Compare to other data collection technologies (e.g.: loop detectors), information from cellular based traffic data collection technologies can be provided with limited accuracy (such systems do not provide absolute traffic volume counts, do not differentiate between lanes, and suffer from low quantity of cellular data during night time) (Avni, 2007).
b. *Privacy issue*: Some techniques require individual cellphone signatures. This procedure threatens personal privacy, and cellphone operators should anonymize the data before being used for prediction.
c. *Limited information*: Cellular networks produce massive amounts of data as by-products of their interaction with clients. However, it is a hard task to infer the purpose of the trip, socio-demographic, economic, and psychological information from the cellular networks data that is needed to explain peoples travel behavior (Bolbol et al., 2010).

In spite of the important efforts in applying handover data for the different purposes, by far handover has been the less exploited source of information for the analysis of urban transport and urban dynamics in terms of understanding the mobility patterns of people and some challenges are still to be addressed by the research community.

In our paper, even though the use of handover information for understanding people's movements is also the goal, a different approach is taken by using handover data to understand the flow of people in terms of the use of the main road infrastructure and the arrivals of travelers to their destination in the morning peak hour. In addition to the handover, we obtained data on traffic volumes and presence of people. We also used the digital road network of Lisbon as the infrastructure supporting flows from/to and between different parts of the city. Road network in urban area is the lowest level of linkage, which is the defining element of the urban spatial structure (Rodrigue et al., 2006).

The remainder of this paper is organized as follows: Section 2 describes the case study area and dataset collection procedures. Section 3 presents the methods that are used in the study. In Section 4, we provide detailed description of the results. In Section 5, we describe the main conclusions and future directions of the study.

2. Data description

A case study area of about 156 km^2 was identified inside the Lisbon Metropolitan Area (LMA), which comprises of the Municipality of Lisbon and its surrounding. Lisbon is the capital of Portugal and the center of the LMA. The LMA has a population of 2.8 million and 18 municipalities with a total area of 2962.6 km^2, where about 20% of the population resides in the Municipality of Lisbon (Correia and Antunes, 2012).