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Simulating human mobility patterns in urban areas

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ABSTRACT

With the rise of smart cities people are moving within urban spaces and still be able to pervasively interact with information, services, city's resources and other people. In such a highly connected scenario, smartphones and other wireless portable devices are carried by humans, exhibit the same mobility behaviour of their human carriers and their movements strongly impact on the underlying network operation and performance. The understanding of human mobility in an urban space has become crucial to optimize the network management, to plan the adaptive allocation of critical resources and ensure constant quality of the user experience. This paper takes a first step in the direction of the design of a mobility model meeting behavioural and scale requirements of modern smart cities. We envision a smart city as a collection of places, each representing a Point of Interest (PoI) with specific value for single individuals and for a set of them. As a consequence, each individual has his/her own mobility footprint, while few of them share similar mobility patterns. By simulating the mobility of each individual across city's places, we will be able to properly describe human mobility and social behaviour in urban spaces, and to extract all needed information about how city's resources and services are accessed. The extensive use of CDR, GPS and WiFi traces, enables us to analyse the characteristics of city's Points of Interest (PoI), classify them for each individual according to their importance and study how the individuals move across them. The common features observed are the key points to build a metropolitan mobility simulator able to reproduce the regularity in spatio-temporal behaviour of mobile users and also how city sociality is built around PoIs of the city. The simulator exhibits high flexibility and can be applied in wide geographical and population scales.

1. Introduction

Understanding the rules that govern human mobility is a crux of many studies in multidisciplinary fields, such as urban planning, traffic forecasting and the spreading of biological and computer viruses [7,25]. Human mobility also determines the formation of social aggregations, so that its awareness is prominent for understanding how specific social networks form and grow [25]. It also came at the forefront of studies in mobile networks because it is at the heart of the decision of the next hop (by predicting the next opportunity) in the design of routing protocols for Opportunistic Networks [13].

The recent growing interest generated by recreating human mobility patterns gave rise to many experiments mainly relying on a variety of mobility capturing technologies to generate traces (see, for instance, surveys [27], banknote tracking [1],

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mobile phone traces [7], global positioning system (GPS) [24], WLAN associations and AP logging [8], Bluetooth connections [3], etc).

Radio technologies, such as WiFi and Bluetooth, and GPS have been widely adopted as position sources because they offer a simple solution to detect the location of an individual with good precision. As a consequence, mobility patterns and features extracted from these traces have been widely leveraged to design several data-driven models ([8,17,26]). The main limitations of all these studies and models is the fact that they have been proposed and validated in limited geographical areas, such as campuses and locations of large events, and they are built upon experiments involving a small number of individuals within a specific area. The recent and massive growth of studies and business models brought together by the quest for new applications and services for smart cities puts the research community in the urgent need to scale up current mobility understanding and modelling to involve larger amount of individuals at a urban, metropolitan scale. This is raising concerns about the feasibility of achieving the mobility requirements posed by smart cities by simply exploiting mobility models derived from proximity detectors in small areas (such as WiFi and Bluetooth).

This paper takes a first step in the direction of the design of a mobility model meeting behavioural and scale requirements of modern smart cities. We envision a smart city as a collection of places, each representing a Point of Interest (PoI) with specific value for single individuals and for a set of them. PoIs are places where the individuals' home and work locations, or the city's resources and services are located. People are used to go back and forth between different PoIs during their urban life experience following their habit, commitments and social behaviour. As a consequence, each individual has his/her own mobility footprint, while few of them share similar mobility patterns. By simulating the mobility of individuals across city's places, we will be able to properly describe human mobility and social behaviour in urban spaces, and to extract all needed information about how city's resources and services are accessed.

Although all available mobility models have in common the fact that people move from place to place, what is still almost unexplored is the characterization of places on a per-user basis. Places are usually modelled as a collection of indistinguishable geographical points [[4,12,15,17,19,21,24], having the same importance for all persons. A few notable exceptions are provided by works where home and work places are considered [9,10,15].

In this paper, starting from the recent study [23] about the relevance that each place has for a particular person, we investigate how to simulate human mobility in a metropolitan area by exploiting the notion of the relevance that a PoI plays in the mobility patterns of an individual. To this purpose, we leverage a large dataset of Call Detail Records (CDR) containing voice-call, SMS and Internet activities of nearly 1 million users of a mobile operator in the city of Milan. The dataset has a few important properties about people and places enabling us to study mobility in a urban mobility perspective. First, the observed population represents the real mass and variety of people living in modern cities. Second, and unlike other similar datasets, the considered tower cells are regularly spread over the whole metropolitan area and cover a smaller area, less than 200 m of radius, w.r.t. other datasets in literature. For instance in [7] the average service area of each tower was approximately 3 km^2, and just around 30% of the towers covered an area of 1 km^2 or less. The latter feature allows us to reproduce movements of people within a city and to fully characterize places due to the high spatial resolution of the data. According to our view, PoIs are at the heart of all mobility patterns in urban space and their relevance attribute is assigned on a per-user base. To validate whether the relevance approach can be scaled down to small environments, we perform the same analysis on widely used GPS and a WiFi datasets.

Relying on extensive analysis on heterogeneous datasets, we show that the proposed mobility simulator properly reproduces mobility patterns at different geographical scale and for different population settings. Synthetic traces are proved to correctly capture real life features and behaviours. In particular, it is able to simulate how people might build relationships loosely by sharing a place. By leveraging the concept of colocation, we will show that our system can simulate how often and how long people share one of their Points of Interest.

2. Related work

Mobility modelling, in most cases, has been accepted as a way to assist simulations of mobility in wireless networks. Mobility modelling can also assist different aspects of network operation, such as handover, resource management, routing, and even a better independent deployment of connectivity models, mainly due to the possibility of understanding human movement patterns and regularities. Prior mobility models that were used popularly for simulation of wireless networks were mainly random mobility models such as Random Walk, Random Waypoint and Gauss Markov model [2]. In these models, waypoints, velocity of mobile users and direction of movement are chosen randomly in the simulation area. By choosing purely random parameters, mobile users are allowed to make rapid and sudden changes in their movement. However, unexpected changes rarely occur in human mobility patterns. As a consequence random models poorly reflect realistic aspects of human mobility and it is ineffective to rely on them for accurate understanding of protocol performance.

Due to the detailed and long-term human mobility traces that capture actual human movement, researchers discarded random models and focused on new trace-based mobility models able to realize real properties of human mobility. Authors in [28] proposed an analytical mobility model which extends the classical gravity-based model. The model estimates commuting and mobility fluxes in daily activity of population at macroscopic level. Although this model realizes mobility and transport patterns observed in wide range of population and geographical scales, it does not retrieve any mobility information at microscopic level. We believe this model is more appropriate for studying movement across countries and across