Mobile Landscapes: using location data from cell-phones for urban analysis

Carlo Ratti[1] (1), Riccardo Maria Pulselli (2), Sarah Williams (1), Dennis Frenchman (1)

(1) SENSEable City Laboratory, Massachusetts Institute of Technology, Cambridge, MA, USA
(2) Department of Chemical and Biosystem Sciences, University of Siena, Italy

***ABSTRACT**: The technology for determining the geographic location of cell phones and other hand-held devices is becoming increasingly available. It is opening the way to a wide range of applications, collectively referred to as Location Based Services (LBS), that are primarily aimed at individual users. However, if deployed to retrieve aggregated data in cities, LBS could become a powerful tool for urban analysis. This paper aims to review and introduce the potential of this technology to the urban planning community. In addition, it presents the 'Mobile Landscapes' project: an application in the metropolitan area of Milan, Italy, based on the geographical mapping of cell phone usage at different times of the day. The results enable a graphic representation of the intensity of urban activities and their evolution through space and time. Finally, a number of future applications are discussed and their potential for urban studies and planning is assessed.*

1 Introduction

"In today's Dublin, you wouldn't need a novelist's omniscience to follow Leopold Bloom, Stephen Dedalus, and Buck Mulligan around the city; you could just track their cell phone usage. And if Leopold could get access to the logs, he could figure out precisely what Molly was up to." (Mitchell, 2003)

Whether you are a techno-enthusiast or not, Mitchell's (2003) e-topia has certainly become a reality in the field of mobile communications. Just look at data from the booming mobile communications industry. According to the European Information Technology Observatory (EITO, 2004), cell phone subscriptions in Western Europe reached 350 million in 2003 (157 million in the USA). In Italy, where the case studies presented in this article are located, the number of users is approximately 54 million (EITO, 2004); i.e., the second largest market in

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[1] Address for correspondence: SENSEable City Laboratory, Room 10-485, Massachusetts Institute of Technology, 77, Massachusetts Avenue, Cambridge, MA, 02139 USA

Europe after Germany. Furthermore, with a total population of 57 million, Italy has one of the highest penetrations of mobile devices in the world.

Why should the urban planning community be interested in the aforementioned data? First, the widespread deployment of mobile communications, supported by personal handheld electronics, is having a significant impact on urban life. People are changing their social and working habits because of the new technology (Rheingold, 2002). Activities that once required a fixed location and connection can now be achieved with higher flexibility, resulting in the users' ability to act and move more freely (for an analysis in the corporate working domain, see Duffy, 1997). As a consequence, urban dynamics are becoming more complex and require new analysis techniques. Second, and more importantly in this context, data based on the location of mobile devices could potentially become one of the most exciting new sources of information for urban analysis.

Locational data are becoming increasingly available and their applications are currently a hot topic in the cell phone industry (see for instance www.lbszone.com). They are generally referred to as Location Based Services (LBS) – value-added services for individuals in the form of new utilities embedded in their personal devices. Examples, both implemented and speculative, include systems providing information about one's surroundings (neighbouring restaurants, museums, emergency shelters, and so on); distributed chat lines aimed at allowing people with similar profiles to encounter each other in space, via a kind of technologically augmented serendipity; and 'digital tapestries' that attach different types of information to physical spaces (see sections below for detailed references). And yet, surprisingly enough, aggregated locational data have not been used to describe urban systems. Research efforts in the area are sparse; the scientific literature mostly ignores themes such as the mapping of the cell phone activity in cities or the visualization of urban metabolism based on handsets' movements. How could this be?

The most reasonable assumption is that scholarly research has been hampered so far by the difficulty of accessing raw data. Also, in most cases, mere data is not enough, and the development of ad-hoc software and systems in partnership with cell phone companies is required. In this study, the research team has had the opportunity to establish a partnership with a leading mobile network operator, thus gaining a privileged insight into how aggregated data from mobile devices can reveal urban systems. The metropolitan area of Milan, Italy, has been selected as the initial case study; this combines a number of interesting planning features with one of the most developed markets for mobile phones.

Results seem to open the way to a new approach to the understanding of urban systems, which we have termed "Mobile Landscapes." Mobile Landscapes could give new answers to long-standing questions in architecture and urban planning - How to map vehicle origins and destinations? How to understand the patterns of pedestrian movement? How to highlight critical points in the urban infrastructure? What is the relationship between urban forms and flows? And so on. The traditional approaches to gaining information about these issues are very costly. Traffic engineers still use extensive (and expensive) surveys to calibrate their models. Space syntax researchers (Hillier, 1996) carefully monitor pedestrian movement in order to gain insight on its correlation with urban configuration. Both fields could be revolutionized by the introduction of Mobile Landscapes, as they would reveal in real time actual patterns of movement rather than models or estimates.

More generally, Mobile Landscapes could have economic consequence beyond urban planning, with potential applications in real-time emergency relief and distributed urban advertising. In the academic community, Mobile Landscapes could complement studies that have proliferated in recent years on the analysis of different types of networks, such as the Internet or wireless hotspots (Wi-Fi). The use of data from cell phone networks has several advantages compared with the latter (cf. for instance Townsend, 2001). First, activity can be directly mapped to the location where it happens, whereas in the case of the Internet it is related to the nominal, sometimes fictitious, location where a domain is registered. Second, data are not geographically static, but can account for people's movements and the intensity of communication activity at different times of the day. Finally, the very high penetration of cell phones in most developed countries makes them an ideal technology to collect large amounts of statistically significant data, more so than the Internet or Wi-Fi.

Before becoming too excited, a review of location based services (LBS) and their underlying technology is required. This paper aims to introduce key concepts to the urban planning community, suggest a preliminary taxonomy, and present initial results. A subsequent paper, currently near completion, will examine more in detail additional applications of Mobile Landscapes.

2 Location Based Services: basics

Location Based Services (LBS) are rapidly evolving and do not fit into a well-established body of knowledge. Different definitions are found in the literature. In general, they are referred to as a set of applications that exploit the knowledge of the geographical position of a mobile device in order to provide services based on that information. More concisely, they have been described as "applications which react according to a geographic trigger" (Whereonearth, 2004) – the latter being the position of a mobile device. Some authors also focus on the individual nature of LBS, stressing their customer-oriented character: providing users with *"a customized service depending upon his geographical location"* (Magon, 2004). Increasingly, it is being acknowledge that the user's geographic context and spatial behaviour could complement simple proximity searches around the current location (Brimicombe and Li, 2002).

The implementation of LBS requires the following components: a technology that allows the determination of a mobile device's position (several options are reviewed in section 4 below); a system to merge location information with a geo-referenced database (usually a Geographic Information System); and, obviously, a wireless communication infrastructure. Historically, LBS have grown on existing wireless networks: therefore, their components are required to be in a form that is easy to integrate into the existing systems and do not interfere with them.

USA and European legislation for emergency relief played a major role in the development of LBS. In 1995, the US Federal Communications Commission launched an emergency services initiative called enhanced 911 (e911). This initiative proposed that the US Congress institute a legislative mandate forcing all mobile network operators to provide services to locate emergency 911 calls (Spinney, 2003; FCC order number 94-102). According to the latest version of the mandate, mobile operators must be able to locate their users within 50 m 67% of the time, and/or 150 m 95% of the time (Spinney, 2003). Great efforts are currently being made to enhance location capabilities of cell phone networks in order to meet the e911 directive.

The European Union has also implemented a programme of its own, defining a set of minimum requirements of enhanced 112 emergency services. From 25 July 2003, under the European Universal Service Directive (Directive 2002/22/EC[2]), fixed and mobile network operators are required to transmit the location of people calling 112 emergency lines, in the best possible way based on the national emergency standards and the technological possibilities of the networks (GIS_news 2003).

3 Location based services: taxonomy

Beyond emergency relief, a large number of commercial LBS are currently being developed: from navigation systems that allow users to find restaurants nearest to them, to collaborative applications that allow spatially distributed chats. Some of these services are starting to be implemented by cell phone companies as *more value added services* – i.e. services that would increase their average revenue per user and, consequently, market demand (Adams *et al., 2003*).

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[2] Directive 2002/22/EC of the European Parliament and of the Council of 7 March 2002 on universal service and users' rights relating to electronic communications networks and services (Universal Service Directive)

In this paper a preliminary taxonomy of LBS is proposed, based on the beneficiaries of the services: single users with mobile handsets, groups of users, or third parties.

3.1 Individual users as beneficiaries

In the simplest configuration, LBS can have a significant impact on people's daily activities by allowing them to navigate through physical and virtual space simultaneously. The mobile device acts as an interface to access remote information (in the form of geo-referenced databases) according to a user's spatial position in the real world. Different types of applications, both implemented and speculative, exist, such as the following:

a. *Navigation aids*. Information concerning a user's position, direction and targets can be interfaced with GIS in order to facilitate orientation in unknown environments. Some of the most popular applications include driving directions and the accessibility of location-dependent tourist information: for example, a mobile guide with content continuously keyed to a user's changing location;
b. *Geographically distributed yellow pages*. Such a service is the natural extension of the one described above. It can provide answers to detailed requests ("Where is the nearest vegetarian restaurant?") or to more complex shopping scenarios designed to match your personal profile and preferences with opportunities at your location.
c. *Educational services*. The access to educational information could be enhanced by the use of locational data. Basic examples are cyber city-tours, campus navigation aides, applications to ease the touring of historic sitesand other community-based environments.

3.2 Groups of users as beneficiaries

When a whole group of users have access to LSB, new applications can be imagined, such as the following:

d. *Distributed chats and friend tracking*. This service allows users to find friends, or people with similar profiles, entering and moving in their region of proximity. A short message is delivered when the distance between two or more associated devices is below a certain radius. New opportunities for chat and meeting/mating services open up.
e. *Location-based gaming*. Computer games that take into account the geographic position of different users can be played on cell phones.
f. *Traffic services*. Information concerning the position of a group of users can be interfaced with traffic monitoring in order to deliver news about congestion and suggestions for alternative routes.

g. *Digital tapistries*. Groups of users can attach information (messages, photos, etc.) to geographic location (see for instance Lane and Thelwall, 2005). When other users move through it, they can retrieve the previously posted data. In some cases, physical signage is also added to help the merging of digital and physical layers: for example, the *Yellow Arrow* project (Yellow Arrow, 2005) allows users to attach commentary to a place marked with a bright yellow arrow sticker: "This is a terrific Italian Restaurant...." The concept is like that of a virtual showcase overlaid onto the city, where virtual messages are posted.
h. *Coordinated actions*. Groups of users can coordinate and adapt to changing environmental conditions – such as protesters during public demonstrations.

3.3 Third parties as beneficiaries

Finally, a number of applications can be imagined when location information is not exploited by cell phone users themselves but by third parties:

i. *Public safety and security*. As reviewed above, call location can be used for emergency services such as e_911 and e_112. Also, applications related to medical and roadside help, as well as other types of assistance, can be imagined.
j. *Family security*. A family locator could keep track of teenage sons, elderly people, disabled members – or even pets.
k. *Emergency relief*. It would be possible to broadcast alerts that vary with geographic location: for instance, would the Indian Ocean tsunami disaster of late 2004 have happened if people near the sea coast had been identified and given instructions via their cell phones?
l. *Business safety and efficiency*. While the term 'employee tracking' found in the literature does not sound promising, it could be applied for the sake of safety, safe-zone monitoring or coordination inside large organisations. For instance, service organizations and transport companies could become more efficient and save time and money by better routing their fleet and personnel, providing improved customer service and gaining a competitive advantage".
m. *Commercial and information services*. Possibly one of the largest potential business applications is that of delivering leisure or commercial information related to the space through which a user is moving. Based on his/her profile and the service he subscribed to, the user could receive highlights about points of interest or special deals at commercial establishments within a certain radius of proximity. Other geographic filters could be applied in addition to geographic proximity, such as accessibility, prediction of future location, visible areas, or other criteria.

n. *Location sensitive billing.* Following the successful introduction of the London Congestion Charge in 2003, road-pricing schemes have become popular with cities, if not citizens, all over the world. They are aimed at managing traffic flows by levying a charge for the use of a certain infrastructure at a certain time. The London system scans the license plate of every vehicle that enters the central zone of the city between 7 am and 6:30 pm Monday through Friday and checks that the owner has pre-paid a flat fee (CC London, 2005). More sophisticated systems allow dynamic road pricing, whereby the fee changes as a function of time, location and environmental variables (such as the neighbouring traffic situation). Dynamic road pricing and location sensitive billing could be provided by cell phone operators on behalf of local governments. Applications could be extended to parking fees, urban event fees (such as concerts and conventions), and ticketing for transport. The result would be like replacing physical fences and entrance gates with digital ones.

o. *Urban systems mapping*. This category exploits the ability of LBS to gather large amounts of data, in anonymous and aggregated form, relating to the location and movement of cell phone users. For the first time it is then possible to visualize 'living cities', complex systems whose dynamics are described based on people's activities and movements in space. Results suggest that this analysis could lead to a powerful tool to understand and control many phenomena occurring in urban areas.

The last category has not yet been investigated and is the focus of the present research effort. Preliminary results are shown in sections 7 and 8 below, while a more extensive discussion of possible applications will be presented in a subsequent paper.

4 How can location information be obtained?

The emergence of LBS is related not only to the development of cell phone networks, but, more importantly, to the availability of location sensing techniques that allow the determination of a user's location. A number of them exist; they are listed and briefly reviewed below, from short range tracking to GPS to cellphone positioning. As can be seen, there is a trade-off between accuracy and ease of retrieving the data. At one extreme, the cell identification method does not provides much precision but is available on most networks and allows locating any user with a cell phone turned on.

4.1 Short range tracking

Indoor positioning technologies are currently the focus of much research attention, as they are the basis of pervasive, context-aware computing systems that enable users to interact more effectively with their physical surroundings. For instance, they allow tasks such as printing a document to the closest printer, or displaying a map of the immediate surroundings and offering guidance inside a building (Bahl *et al.*, 2000, Ward *et al.* 1997). Furthermore, information about the location of staff members in places such as large office buildings or hospitals can help a receptionist coordinate activities (Want *et al.,* 1992).

The tracking of people in indoor positioning systems typically relies on the propagation of a physical wave phenomenon (Harle *et al.*, 2003). A number of different technologies exist, as explained hereafter. Infrared (IR) systems are based on badges emitting a unique IR signal at fixed intervals (for instance, every 10 seconds), which is then picked up by sensors placed at known positions and relayed to location software (Bahl *et al.*, 2000). Opposite schemes are also possible, where IR transmitters are placed at known positions and their emitted signal is detected by carried sensors (Azuma, 1993). A similar technique is based on radio frequency (RF) signal strengths (see for instance the Duress Alarm Location System, DALS, by Christ *et al.*, 1993, and the 3d-iD RF tag system built by the PinPoint Corporation, Werb *et al.*, 1998).

Also, a number of methods are being developed to determine the location of a user by processing information gathered by wireless networks (Wi-Fi). Three basic ways can be used. First, it is possible to infer location information from the coordinates of the antenna (hotspot) to which one is connected, with an accuracy proportional to the antenna density in the system (Hodes *et al.*, 1997). Second, signal strength information gathered at multiple receiver locations can be used to triangulate the user's coordinates (Bahl *et al.*, 2000). Third, it is possible to map the observed signal strength of fixed beacons placed throughout a building. In this case, the position of a user can be inferred by measuring the signal strength of all access points within range and then searching through the radio map to find the location that best matches the measured signals.

4.2 Global Positioning System

The Global Positioning System (GPS) is a locational infrastructure based on Navstar, a constellation of 24 satellites operated by the U. S. Department of Defense. A land-based GPS receiver uses signals from these satellites to determine its location. Usually, a minimum of four GPS satellites are viewable from anywhere on the earth's surface (provided that there are no obstructions such as buildings), thus enabling the receiver to calculate its own position via triangulation – i.e. by measuring the time needed for a radio signal to reach the GPS handset from at least three satellites. The U. S. Department of Defense had initially scrambled GPS signals for civilian use, thus introducing error into its resulted positional accuracy. However, the practice was discontinued in 2000 and since then GPS achieves an accuracy of ten meters or less (Spinney, 2003).

Recently, the industry has started producing mobile phones with GPS. They provide high-resolution geographic positioning for most of the globe, without being dependent on any fixed terrestrial infrastructure. Users' location can be identified even in remote areas not covered by wireless networks. The disadvantage of the technique, however, is that it requires additional hardware for capturing the satellite signal and that it is not available in indoor places or in highly-built urban environments.

A new satellite navigation system is currently being developed by the EU and is scheduled to become operational in 2008. It is named Galileo and it would complement GPS by allowing a higher level of accuracy and extended coverage at extreme latitude. An agreement between the USA and the EU was signed on 27 February 2004 to facilitate the joint use of the two systems[3].

4.3 Assisted Global Positioning System

Assisted Global Positioning System (A-GPS) is a locational device that uses both GPS and a terrestrial cellular network to obtain geographic position. This operation enhances the functionality of the handset by indicating "*where the appropriate satellites are and allows the network to assume much of the calculation role that would otherwise be performed by the handset*" (ACA, 2004). Therefore, an accuracy of 3m or better in open air environments and 20m under dense canopies can be achieved (Moeglein and Krasner, 1998). According to Spinney (2003), "*the A-GPS mobile positioning techniques offer the best technology to date. However, the system is a costly investment for mobile networks and it requires new infrastructure and device technology enhancements*".

4.4 Cellphone network positioning techniques

GPS and the other techniques reviewed above might be central to the development of LBS in the future. At present, however, they are not widespread. GPS phones, in particular, while commercially available today, are not generally forecast to conquer the market for a few years. Therefore, most LBS need to extract location information by exploiting cell phone networks. How could this be done?

Let's review how a network works: "*mobile networks, traditionally referred to as 'cellular' networks, consist of 'cells'. Cells are essentially geographic radio frequency (RF) signal serving zones around a tower or base station. Each cell within a cellular network is geographically defined by the range that RF signals propagate to continuous*

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[3] U.S.-EU Joint Statement on GPS/Galileo Cooperation, distributed by the Bureau of International Information Programs, U.S. Department of State on 27 February 2004. web site: http://usinfo.state.gov

space. When a mobile phone user is moving and enters a serving cell, network base stations are designed to recognise that the user is within the serving proximity of the station's neighborhood. The base station then automatically 'locks on' to the mobile, and 'hands off' the call from one base station and corresponding cell to the next base station and serving cell within the network." (Spinney 2003)

According to the same author, there are two major ways for mobile positioning in such a network, referred to as network-centric and device-centric (Spinney, 2003). In network-centric systems one or several base stations make the necessary measurements of distance to a cell phone and send the results to a centre where location is calculated. In device-centric systems the handset performs the calculation itself based on environmental information gathered from the network (Horsmanheimo, 2001, CGALIES, 2002). Hybrid solutions are also possible, trying to combine the advantages of both systems: for instance, the mobile device performs position measurements and sends results to an external centre in the network for further processing through powerful processors.

Device-centric techniques let individuals perform their own position calculations and provide high levels of accuracy; however, they require additional hardware and software to be added to each device. To the contrary, network-centric techniques exploit available information – so they do not require modifications of handsets; they can be implemented through ad-hoc hardware and software in the base stations of the network infrastructure (ACA, 2004).

According to the American National Standard Institute (ANSI) and the European Telecommunications Standards Institute (ETSI) location finding systems can be classified according to the following technologies: cell identification, angle of arrival, time of arrival, enhanced observed time difference and assisted GPS (CGALIES 2002):

a. *Cell identification***.** The first and simplest way to locate a cell-phone is just to identify its serving cell. Then, the available coordinates of the serving base station are associated with the mobile device. Using this technique, the accuracy of the locational information depends upon the physical architecture of the network, i.e. the size and density of cells. Systems with smaller cells allow a higher precision; the accuracy can go from 100m to 600m and more (for example in certain rural areas). Problems may arise because of the nature of radio-communication propagation: for instance, the serving cell may not always be the closest to the user (ACA, 2004). However, despite this fact and a general coarseness, the Cell-ID method has a great potential for LBS, as it does not require modifications of handsets or networks and it is very easy to implement.

b. *Angle of Arrival.* The AoA method uses data from base stations that have been augmented using arrays of smart antennas. The latter allow the determination of the angle of incoming radio signals. It is then possible to determine the location of a handset by triangulating known signal angles from at least two base stations. The estimated accuracy is between 150 and 50 m; however, it is necessary to take into account the fact that small angular errors can translate into significant positioning inaccuracies if the cell-phone is far from the base station. (CGALIES 2002). According to most authors, the accuracy is often above 125 m and the time needed to locate a user is about 10 seconds. Angular information could be also combined with distance estimates from the time of arrival technique described below - so just one base station could be used.

c. *Time of Arrival.* This technique builds on cell-identification positioning and includes one additional dynamic variable – Time of Arrival (ToA). The location of the base station is coupled with distance estimated from the time needed for the radio signal to reach a device and back (ACA, 2004; Spinney 2003). ToA can only be used to estimate location if the cell radius is greater than 500 m so that it generally works for rural and sub-urban areas. Distance (d) is obtained knowing the velocity (v) of the signal and its time (t) of arrival ($d=vt$). Position is determined by triangulation from three base stations that have been finely synchronized. When compared with the cell ID method, ToA techniques do not offer a very significant increase in performance; furthermore, their accuracy may vary depending on the geographic distribution of base stations, signal strength and environmental conditions (e.g. topography and weather).

d. *Enhanced Observed Time Difference (E-OTD)* is a device centric positioning technique that assumes that handsets are endowed with software that locally computes location. Three or more synchronised base stations transmit signal times to the mobile device, whose embedded software calculates time differences and therefore distance from each base station. E-OTD mobile positioning techniques are in the range 50-125 m (CGALIES, 2002).

5 Privacy issues

What about privacy? The first concern of a newcomer to LBS may be that his or her movements can be tracked. One can imagine stories proliferating about jealous lovers spying on their partners through hidden, trackable cell-phones.

First, it is important to state that the Mobile Landscapes project, described in this paper, does not infringe in any way on the privacy of cell phone users. All analyzed data are received and treated in aggregated and anonymous form, according to the European regulations, so that it would not be possible in any way to link location data with real people. Also, one of the ongoing goals of the project is to develop a code of conduct that will address privacy issues that might arise during the course of the investigation. The overall aim of the project, far from encouraging individuals to be tracked, is to see how LBS could provide useful information to improve life in urban communities.

Most concerns about privacy relate to personal and group services (sections 3.1 and 3.2). In general, such services need to comply with directives regarding privacy in telecommunications, such as those issued by the European Union. The European Union distinguishes between three families of data: *traffic*, *personal*, and *location data*. *Traffic data* are those processed 'in the course of' the transmission of a communication over a communication network (Directive 97/66/EC). *Personal data* are those concerning the subscriber and also his extended personal profile (Directive 95/46/EC). *Location data* are those processed indicating the geographic position of the device (Directive 2002/58/EC). In particular, Directive 2002/58/EC provides regulations about location data in article 9, where it states: "*such data may only be processed when they are made anonymous, or with the consent of the users or subscribers to the extent and for the duration necessary for the provision of a value added service. The service provider must inform the users or subscribers, [...] of the purposes and duration of the processing and whether the data will be transmitted to a third party for the purpose of providing the value added service*". (DIR 2002/58/EC[4]).

Fisher and Dobson (2003) highlight that most privacy concerns appear when personal location data are made available to third parties other than the mobile phone operator. Several studies have demonstrated that such data sharing carries both risks and advantages. In general, location data sharing with a third party is most acceptable when the third party has rights or responsibilities in relation to the person being tracked (for instance, a child or elderly person), or when the person has assented to be tracked. This might include cases in which a user is in a contractual relationship, such as employment, to the third party. An example is the tagging of vehicles in a company fleet. Another example is the popular LBS application of 'friend tracking', which allows a subscriber to receive information about nearby subscribers and eventually to contact them. This practice requires a subscription by users who are willing to join in the service; Fisher and Dobson (2003) state that "*each individual should be able to negotiate access by another person to information about their location. No one else should be able to circumvent that right*".

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[4] Directive 2002/58/EC of the European Parliament and of the Council of 12 July 2002 concerning the processing of personal data and the protection of privacy in the electronic communication sector (Directive on privacy and electronic communications)

In general, authors approach the privacy issues related to LBS in different ways. The extreme views of Dobson and Fisher (2003*)* describe a new form of slavery based upon location control, named Geoslavery, contravening Article 4 of the Universal Declaration of Human Rights[5]. In today's context, it would be easy to see the dangers of discriminatory applications of tracking to disadvantage particular groups based on who they are and where they go - think about Muslim men. More nuanced approaches highlight how *"informed scepticism about cartographic surveillance should encourage the vigorous yet vigilant application of this ambiguous technology that can do far more good than harm, if controlled"* (Monmonier, *2002)*. Also, Spinney 2004 highlights the benefits of corporate or communal applications, where location is controlled in order to provide benefits not to individuals but to groups (companies, for instance, could operate more efficiently, saving time and operational costs).

The Mobile Landscapes project is an example of a communal application of LBS. As highlighted above, it makes use of anonymous, aggregated data so that individual movements cannot be tracked and therefore individual privacy is not an issue.

6 Mapping of digital networks

As noted above, mapping cell phone data can reveal patterns of activity and interaction in the city potentially of great value to urban planning and design. Yet to date little use has been make of this tool. This may be due to the difficulties of establishing a partnership between academics and network operators. However, the mapping of other types of digital networks has been a fertile field of research in recent years.

A number of scholarly efforts have focused on the Internet (see for instance Batty, 1990 and 1993). Maps have been produced showing the spatial distribution of IP address ownership. *"The invisible territories of the internet do have a geography"* state Martin Dodge and Narushige Shiode (Dodge and Shiode, 1998a), drawing an analogy between cyber and real space (Dodge and Shiode, 1998b). Their method uses GIS analysis functions to explore spatial distribution patterns of a large number of computers, geographically located based on their IP address, and to finally investigate the Internet geography.

Anthony Townsend has published extensively on the geography of digital network from global to urban scale. *"Urban telecommunications infrastructure is now characterized by a much more widely diffused set of access points*

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[5] http://www.un.org/Overview/rights.html / passed as Resolution 217 (III) of 10 December 1948. "No one shall be held in slavery or servitude; slavery and the slave trade shall be prohibited in all their forms".

to global connections. An equally varied array of new infrastructures systems has been developed and deployed to support these activities" (Moss and Townsend, 2004). This study includes the analysis not only of wired but also of wireless Internet in the city and its implications for urban planning as a *"more flexible, intuitive and efficient form of connecting users to networks in everyday urban settings"* (Townsend, 2003). A number of other authors have focused on wireless networks. For instance, the 'Urban Infoscapes' project at Harvard Graduate School of Design, introduced at the Open Source City exhibition (2004), included, amongst others, a Wi-Fi sniffing exercise: mapping hotspots and radio signal intensities on the MIT and Harvard campuses, in order to better understand the new boundaries produced by the overlay of a Wi-Fi infrastructure onto an existing built environment.

Efforts to map wired and wireless networks are basically investigating static phenomena. LBS applications and the Mobile Landscapes project are very different, because they are focused on tracking movement. The differences and potentials have been highlighted in several recent art experiments using GPS. At the Inaugural Architectural Exhibition of the Barcelona Museum of Modern Art in 1995, for instance, Laura Kurgan installed a real-time GPS on the roof of the building and data were stored, processed and displayed onto the walls of the gallery for the entire time of the exhibition (Kurgan, 1995). Another example is the Amsterdam Real Time project (Figure 1), which aims to construct a dynamic map of Amsterdam based solely on the movement of people carrying a GPS device and being tracked in real time. The underlying idea, developed for an exhibition, is that "*every inhabitant of Amsterdam has an invisible map of the city in his head. The way he moves about the city and the choices made in this process are determined by this mental map. Amsterdam Real Time attempts to visualize these mental maps through examining the mobile behavior of the city's users"* (Polak *et al.* 2002). In a certain sense, the approach underlying Mobile Landscapes is similar to the Amsterdam Real Time project, although it does not rely on GPS or other hand held devices distributed to selected individuals. Conversely, it builds on the pervasiveness of cell phones to capture extensive urban dynamics. To date, it seems the only experiment of this kind, apart from a limited case study currently being carried out in Estonia (Ahas and Mark, 2005).

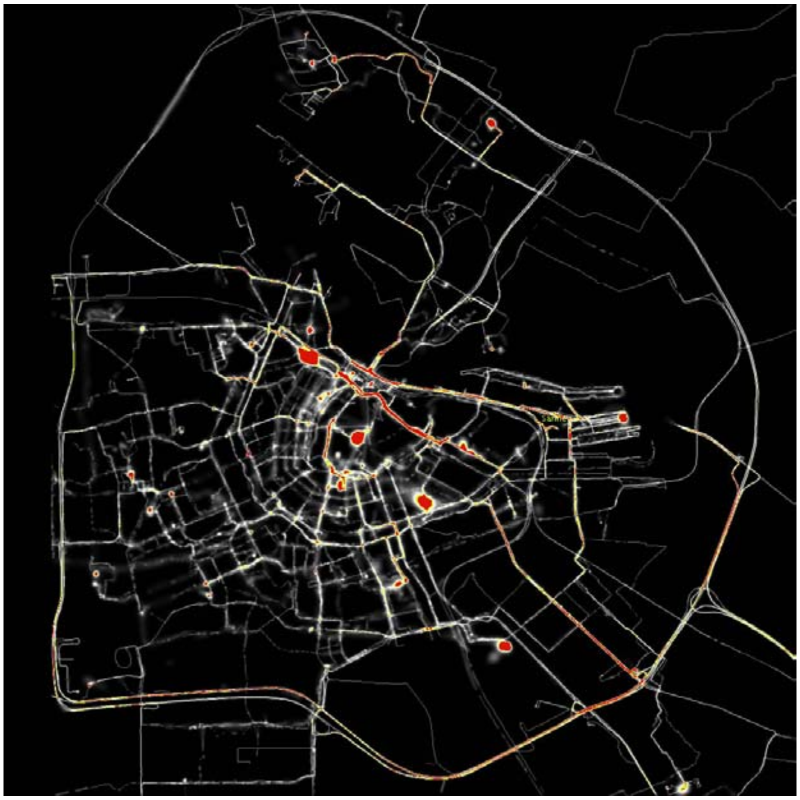

Figure 1 – Amsterdam Real Time project; image from www.waag.org/realtime/

7 Milan: a case study

After the introduction of the basics of Location Based Services, some preliminary investigations of a case study in Milan, Italy, are presented. A joint research project was carried out in partnership with a major European telecommunications company addressing the following question: how can location data from cell-phones contribute to urban understanding?

A case study area was identified of approximately 20x20 km square around the centre of Milan. Apart from its theoretical appeal, the choice was suggested by the interest of the local government in the project and by the high level of cell phone use – which in Italy is one of the highest in the world. Also, the size of the study area, including the city and some inner suburbs, was large enough to highlight interesting metropolitan dynamics without being overwhelmingly difficult to analyze.

The chosen temporal framework was that of 19 April - 4 May 2004 (16 days). This time interval seemed extensive enough to highlight a number of interesting patterns, such as those happening with day/night and working/weekend periodicity. It also included some ‘anomalies’ that could be worth investigating:

a. 25 April, the so-called Liberation day, celebrating Italy’s liberation from Fascism on 25 April 1945. Between 150,000 – 200,000 people rallied from 2 pm onwards through the city around landmarks including: Porta Venezia, Corso Buenos Aires, Piazza San Babila, Corso Vittorio Emanuele, Piazza Duomo.

b. 1 May, Labour day and Euro Mayday Parade. Between 50,000 to 100,000 people rallied from 2 pm at sites including: Piazza Ticinese, Corso Porta Ticinese, Via Torino, Piazza Duomo, Arena, and the central Piazza Castello, where a large crowd assembled in the evening.

c. 2 May. The Milan soccer team won the Italian 2004 league championship after a debated Milan vs. Roma match. Approximately 85,000 people gathered from 2 pm onwards at the San Siro Stadium; later, starting approximately 5 pm, celebrations took over the city center, notwithstanding the rainy weather.

What type of data from cell phones could be mined? As a first step, it was decided to explore data that is normally collected by cell phone operators in the running of the infrastructure and that is thus easily available. The question would then be how to convert it to a revealing format conducive to urban investigations.
For instance, cell phone companies collect traffic data at each base station. On the Milan case study, we received strings such as those presented in Figure 3. Details are in Erlangs[6], a standard measure in the telecommunications industry. Also, the cell ID column does not refer to a whole base station, but to its individual sectors; each of them cover approximately 120 degrees of radio emission, as shown in Figure 2. A standard base station is composed of three sectors, though in some cases, when full coverage is not required, the number could be reduced to one or two (the Milan case study contains 232 base stations or cells, equivalent to 1071 sectors). An additional geographical database allows the translation of Cell ID into latitude and longitude values, as shown in Figure 4.

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[6] The Erlang, named after the Danish mathematician A. K. Erlang, is a dimensionless unit of measurement of traffic intensity in a telecommunications system. One Erlang is the equivalent of one caller talking for one hour on one telephone. For example, 60 calls in one hour, each lasting 5 minutes, results in the following number of Erlangs:
minutes of traffic in the hour = 60 x 5 = 300
hours of traffic in the hour = 300/60 = 5
traffic figure = 5 Erlangs
In other terms 1 Erlang of traffic can be obtained through one single call one hour long, two calls half a hour long, 120 calls half a minute long, and so on.

Also, each antenna records the users who are connected to it, ready to engage in a phone call or a text message. For each user, therefore, it is possible to record their history of movements through the network. Data are stored in the form presented in Figure 5. As can be seen, information is fragmented. If a user only makes two calls a day, one in the morning and one in the evening, then only two points will be revealed onto his/her daily trajectory.

A more sophisticated procedure would allow the continuous tracing of users' movement and is currently being developed with the cell phone operator as part of the Mobile Landscapes project. In this study individual cell phones can be paged at regular intervals, in order to detect to which antennae they are connected in anonymous form[7]. As long as the user's phone is powered on, the location would be known, allowing users to be traced through the city. It is important that the paging uses a code such as not to trigger any beeps or ring tone. The Milan network infrastructure is rather robust, so an experimental case study could withstand paging tens of thousand of users at 5 or 10 minute intervals (in order not to lose accuracy, the minimum interval should be approximately the average time a user takes to move from one cell to the next one). In more refined systems it would be possible to identify fast moving agents and thus implement dynamic update periods, responding to individual movement patterns.

The paging method, as described above, could result in data detailing the traces of individuals through a given region. This method could be considered a large-scale version of the Amsterdam Real Time project previously described. However, the data would be collected seamlessly (i.e. without the need of ad-hoc devices as in the Amsterdam Real Time case) and also on a magnitude never explored before. For the first time it would be possible to visualise in real-time the movements of cities – a long standing dream of traffic engineers, infrastructure designers, emergency relief managers and many others. Results of this experiment, currently in progress, will be the focus of a subsequent publication.

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[7] The anonymity of data is very important, in order to comply with European directives on privacy. The only information processed in this study is that of anonymous identifiers, not of individuals or cell phone numbers. Such an approach, of course, comes at the cost of not knowing potentially interesting demographic data, such as gender, age, etc.

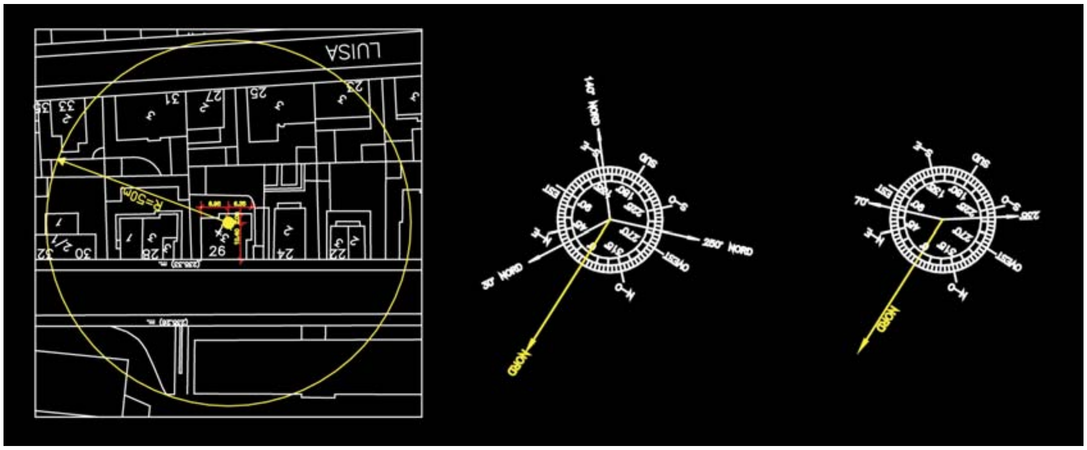

Figure 2 – Cell phone networks: drawings showing the coverage area of a base station and its subdivision in sectors with different orientations

DAY	HOUR	CELL ID	erlang
19/04/2004	8 am	10012	5,85
19/04/2004	9 am	10012	14,71
19/04/2004	10 am	10012	16,25
19/04/2004	11 am	10012	14,06
19/04/2004	12 am	10012	15,82
19/04/2004	1 pm	10012	14,36
...	...	...	...
19/04/2004	8 am	10021	1,91
19/04/2004	9 am	10021	2,89
19/04/2004	10 am	10021	4,68
19/04/2004	11 am	10021	4,23
19/04/2004	12 am	10021	5
19/04/2004	1 pm	10021	5,67
...	...	...	...

CELL ID	X	Y	lat	long
10001	512552,41	5034529,88	45,463333	9,160555
10002	513010,77	5033419,81	45,453333	9,166389
10003	514484,65	5034780,92	45,465555	9,185278
10004	513026,47	5036320,8	45,479444	9,166667
10005	515024,82	5035924,06	45,475833	9,192222
10006	515912,52	5036913,81	45,484722	9,203611
...	...	...	...	...
10012	514101,51	5031323,6	45,434444	9,180278
...	...	...	...	...
10021	514413,27	5037496,56	45,49	9,184444
...	...	...	...	...

Figure 3 – A sample of traffic at base stations on the Milan case study – taken from strings as received from the cell phone operator

Figure 4 –A sample of the spreadsheet connecting Cell ID into a GIS coordinate system (values have been scrambled for security reasons)

User ID	Time	Cell connected to ID

Figure 5 –Record structure of the data showing users connecting to different base stations. Note how user identifiers have been masked, impeding the linkage with real telephone number or other personal information.

8 Data analysis

What information can be gleaned, from an urban studies perspective, from Figure 3, Figure 4 and Figure 5? Let's start with the traffic data on base stations, which seems interesting by itself. When plotted as in Figure 6, it provides a kind of signature showing the intensity of traffic at a given position in space (i.e. the location of the base station) through one whole day. Other temporal frameworks could be used, such as a week, a month, or different aggregates (weekdays, weekends, holidays).

A possible study would be to use this data to infer information about the 'character' of a neighborhood where the antenna is placed. At a simplistic level, districts with base stations showing a prevailing use during working hours are likely to have an office/business nature. Neighborhoods with high evening and early morning cell phone traffic are likely to have a stronger residential character. On the other hand, residential neighborhoods with high cell phone use during business hours may reveal emerging live-work situations. In order to verify this assumption, the plot shown in Figure 6 has been normalized and divided by the total load of calls on the network at a given time. Then, activity at a given base station can be seen as the 'share' of the total activity in the whole region.

Another normalization seems useful: dividing the results by the average activity intensity of the base station under consideration. This normalization standardizes all signatures and allows their comparison (it would be otherwise difficult to plot together data from base stations with different loads). Results could be called 'relative intensity' of cell phone activity. They seem interesting, as the difference in the time patterns of cells can be very strong. Figure 7 and Figure 8 show, respectively, cells with prevalence of activity during the evening and night time (8 pm to 8 am) and during office hours (9 am to 1 pm and 2 pm to 6 pm). The classification could become a powerful tool, if it is linked to the residential or office 'character' of a neighborhood. It would be a novel version of traditional city council surveys, which more often than not take so long to accomplish that they are always out of date. Also, they could monitor trends in the usage of the city in almost real time, prompting ad-hoc action in terms of regulation from the local authorities.

The visual comparison of results obtained with a map of Milan seems logical. However, the correlation between cell activity patterns and the residential/tertiary functioning of a given neighborhood would require a thorough validation. Temporal signatures should be further analyzed and GIS could be used to link them to traditional urban databases; this still remains to be done.

Another use of the data on antenna activity is to elaborate geographical plots. The results could be like thermography maps, highlighting the intensity of cell phone activity in Milan, as shown in Figure 11. How was this map produced? Raw data in Erlang was normalized, as explained above, in order to obtain the 'relative intensity' of cell phone activity. Then values from each base station were plotted geographically using GIS. Instead of simply adopting the coordinates of a base station, a more refined algorithm was developed to further increase the level of accuracy of the mapping. Each station was split into its constituent sectors (normally three antennae, as reviewed above, Figure 2), each of which was mapped at the center of gravity of the area covered by its radio signal. The coverage area of the cells could be assumed as a circular sector of 120 degrees and a distance of 400-500 meters from the antenna. Each of these centroids was used to georeference activity from antennae. Consequently, every site, previously described as a series of sectors (the signal coverage from an antenna) around a unique center (the base station), was split into its constitutive sectors (usually three) and plotted in a more detailed scale, as a series of points instead of one. As a result, the accuracy of the map was such as the distance between the cells centroids instead of the distance between the base stations (Figure 9). Finally, the map with discrete values was interpolated, in order to produce a continuous surface of cell phone activity (Figure 10; intensities are represented by a standard logarithmic colour map from blue to red).

Clearly, the most interesting aspect would be to see the variation in time of the above maps. For instance, Figure 12 shows the evolution over the whole Milan case study between 9 am and 1 pm. Note how it highlights commuting patterns: the relative intensity of calls is maximum in the suburbs early in the morning, while it progressively moves towards the city center and peaks at the core central district (mostly offices) at noon. Also, finer grain dynamics can be highlighted. Figure 13 represents a zoom into the area around Milan's 'Stazione Centrale', a key railway commuting node. Here again it is possible to identify rush hours clearly, with 4 and 5 pm showing a great yellow spot (the last image of the sequence shows low levels of activity, as in fact happens once daily commuters have departed).

The underlying assumption is that the activity of a cell phone station is somehow related to the number of people in the neighborhood. This would be correct if all people were using cell phones at regular intervals. Almost everyone carries a cell phone in Italy, but patterns of use depend on the type of users (age, socio-economical category, etc.) and on the activity they are involved in (working, shopping,...). Still our hypothesis is that the patterns of cell phone intensity correlate with the intensity of urban activity; revealing them can help monitor important urban dynamics. Critical points in the use of the urban infrastructure can be highlighted, as well as special events. Finally, a long-standing problem can be addressed: that of estimating flows in and out of the city: patterns of daily commuting, weekday versus weekend activities, holiday movements. Real time applications could also have new uses in emergency relief, based on broadcast alerts that would be different from one region to the other.

Applications are just postulated here. As presented, the maps simply show dynamics of cell phone intensity. As such, they are accurate and extremely interesting; however, they would need further validation. The new data that are currently being processed, based on the tracing of the displacement of hand held devices in the city at regular intervals (such as every five minutes), will provide evidence of how the overall antenna activity relates to urban movements.

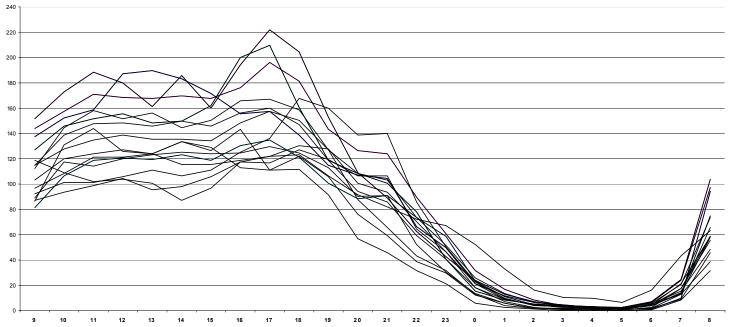

Figure 6 –19 April 2004, Milan metropolitan area. Cell activity, absolute values in Erlang. 1 Erlang = 1 call x 60 min = 2 calls x 30 min, etc

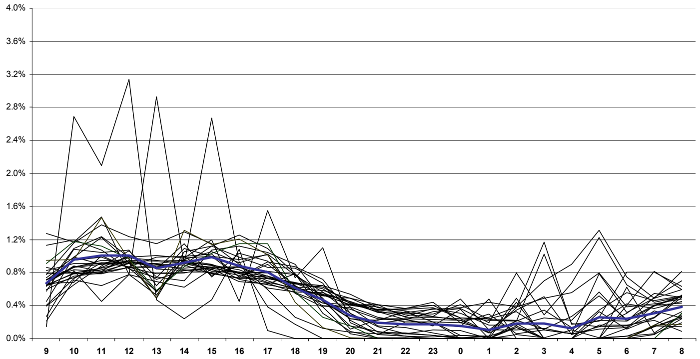

Figure 7 – Cell activity – group of cells with prevalence of activity during the office hours (criteria: respect to the daily average, the gap of activity from 9 am to 1 pm and from 2 pm to 6 pm is more than +20%). The graphic is based on relative values normalized with respect to: the average of activity during the day (the totality of hours) for each cell / the average of activity for the whole region (the totality of cells) for each hour of the day.

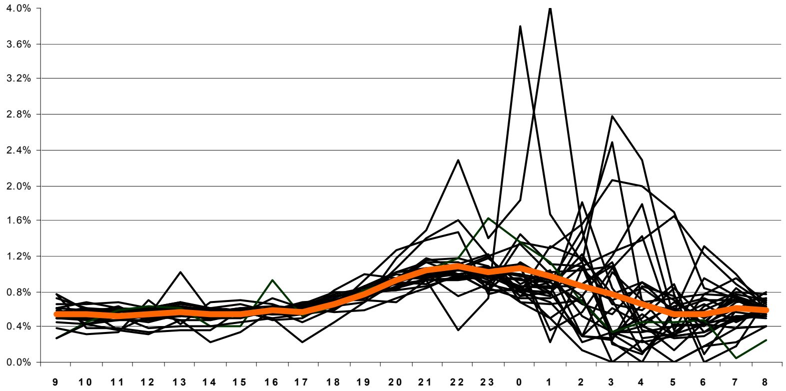

Figure 8 – Cell activity– group of cells with prevalence of activity during the evening and night time (criteria: with respect to the daily average, the gap of activity from 8 pm to 8 am is more than +60%). The graphic below is based on relative values normalized respect to: the average of activity during the day (the totality of hours) for each cell / the average of activity for the whole region (the totality of cells) for each hour of the day.

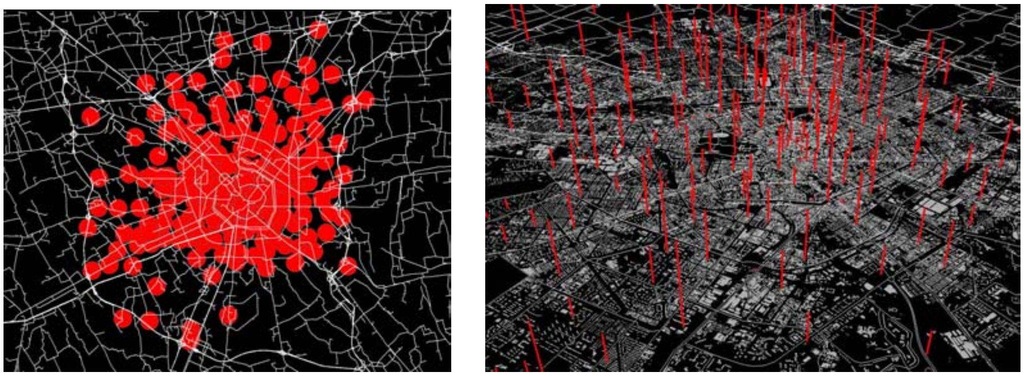

Figure 9 – Geographical distribution of base station positions in Milan (left) and 3-D graph showing their activity at a certain time.

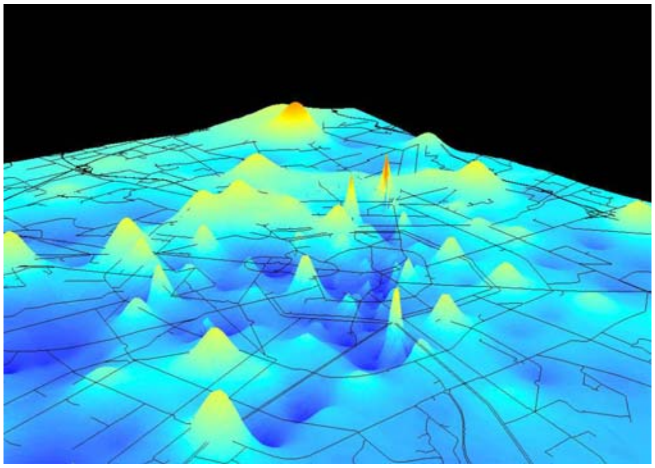

Figure 10 – Geographical interpolation of the data shown in Figure 9 above.

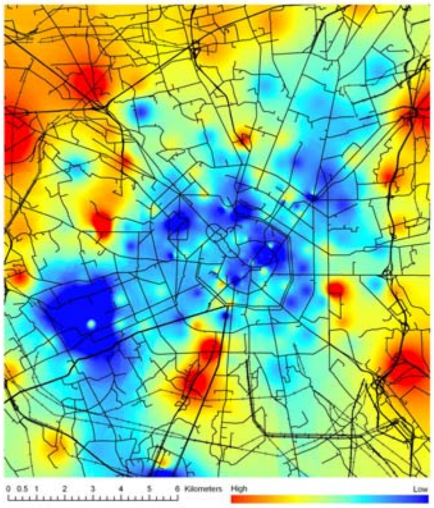

Figure 11 –Map showing areas with different cell phone call density in the metropolitan region of Milan (20x20 km).

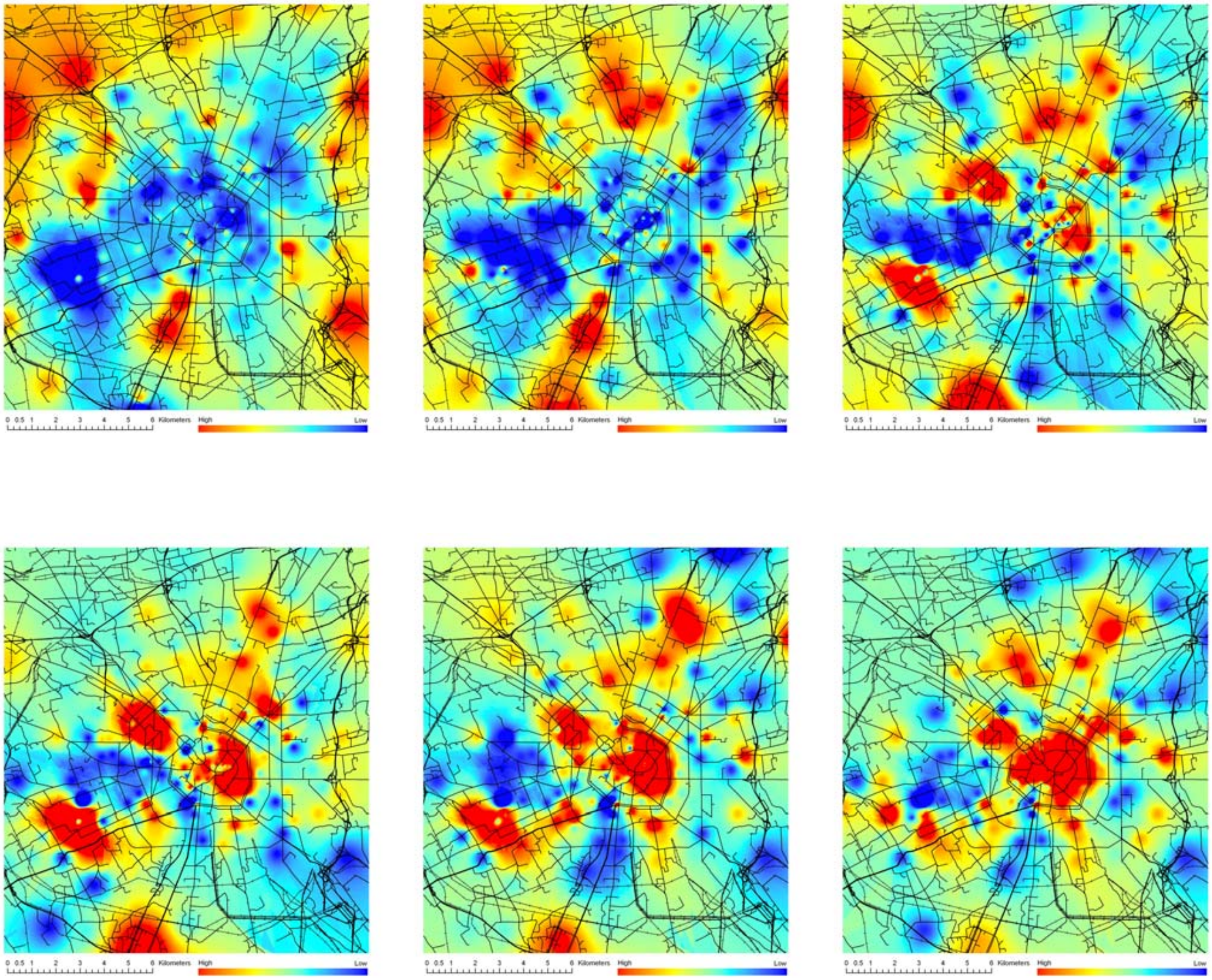

Figure 12 –Maps showing areas with different cell phone call density in the metropolitan region of Milan. Data between 9 am and 1 pm.

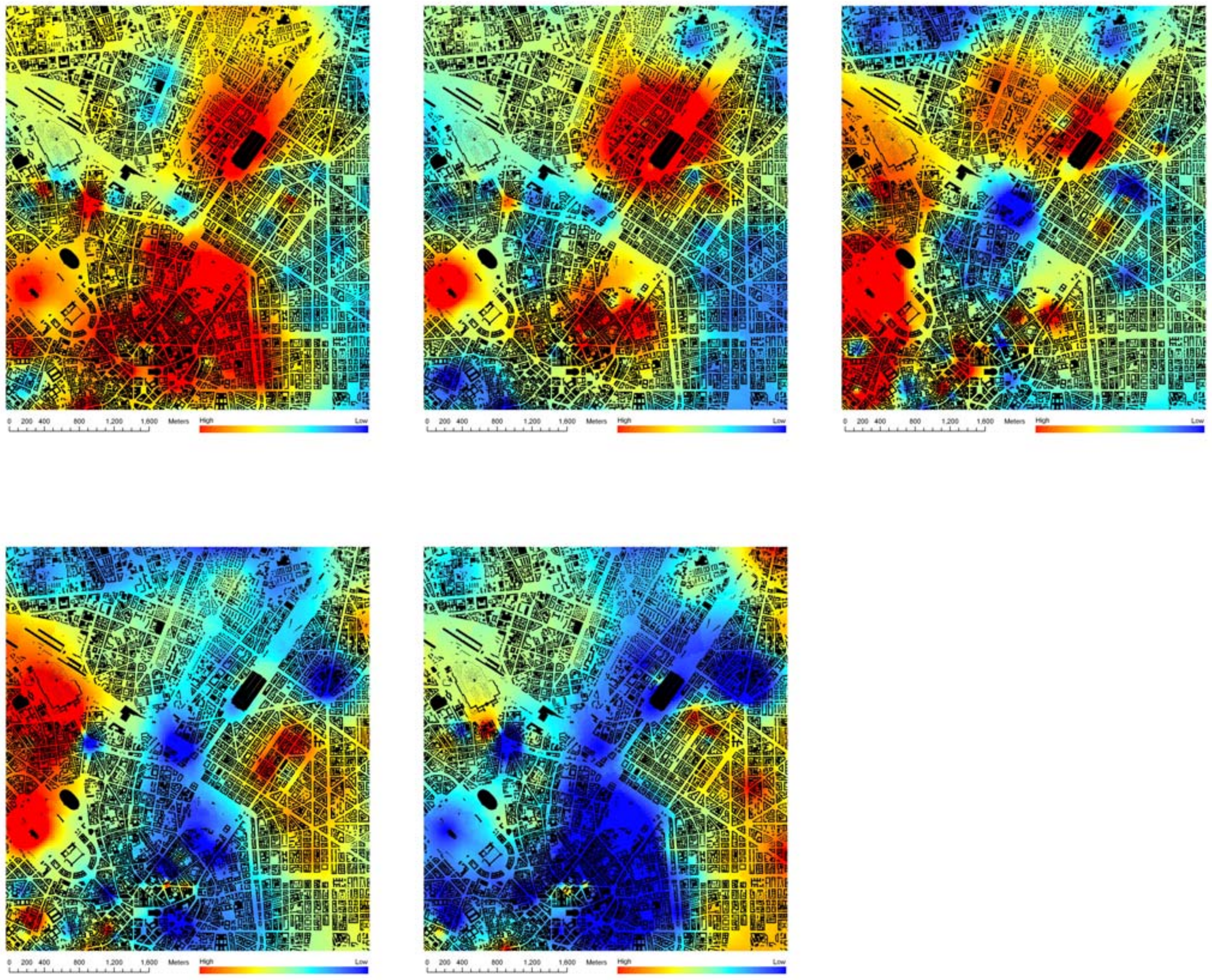

Figure 13 –Maps showing areas with different cell phone call density in the metropolitan region of Milan. Data between 4 and 8 pm.

9 Conclusions and future work

This paper started from the observation that despite a booming mobile communications market, data from cell phones have scarcely been used in urban analysis. Thus, the aims of the paper are twofold. First, it is meant as a review of the growing field of Location Based Services (LBS) for the urban planning community. It provides some definitions, suggests a preliminary taxonomy, summarizes the state of the art in location determination techniques, and discusses some implications related to privacy. Second, after having recognized a lack of research in the application of LBS to urban studies, the paper presents the first results obtained from the Mobile Landscapes project for a case study based in the metropolitan area of Milan, Italy.

Results seem to open a new promising line of urban research. Making sense of the unlimited flow of data from the cell phone infrastructure in the urban context is still unexplored territory. Through the analysis of data coming from base stations, urban planners can gain the ability to monitor rapidly changing urban dynamics, which are difficult to capture by traditional surveys. With the massive spread of hand held devices in the past years, the cell phone infrastructure could provide an unlimited source of information about the city in ever-finer detail. The challenge for urban researchers is to learn how to exploit this information to gain a better understanding of the city.

The technique and analysis presented here only deals with cell phone activity, and some interpretation and validation effort still needs to be done. Grounding and calibrating preliminary data with more conventional urban information will be a necessary next step. Also, the research has so far been limited to readily available data, gathered by network companies. The most promising next step will come from ad-hoc experiments run in partnership with the cell phone operator. We are currently working on the tracing of urban movements based on the paging of handsets. This is done in aggregated form, in order not to undermine individual privacy, with a resolution of a few hundred meters.

We are also planning to develop the system to work in real time (i.e. mapping stream data, while they are collected). Then it would be possible to adjust the timing of data, which at the moment has been set to a few minutes, according to the movements: instead of adopting a regular pace of 5 to 10 minutes, tighter paging intervals could be applied to fast moving agents and vice versa with slow moving ones. This type of analysis could provide for the first time a full and real-time monitoring of urban traffic and beyond. It could highlight how urban systems react and self-organize in response to local disturbances and external actions: a disaster, a concert or a soccer match, a street closing for road-work, the opening of a new building with a certain urban function, the expansion of the wireless network, a new public transport line, and many others. Moreover, the provision of real time services can play a significant role for public safety in case of emergencies. As location data will become increasingly available in the coming years, the question will arise on who owns them and can gain access to them. The exploratory research described in this article was made possible through the partnership with a cell phone operator. But it is envisaged that future regulations will make data more publicly available to the scholarly community and beyond.

As a broader research effort, the Mobile Landscapes project seems to be of topical relevance. The pervasive deployment of new technology is transforming urban patterns, making them more complex and fluid. Greater mobility and freedom are changing the way of living and using public and private spaces. As stated by Batty (2003)*: "Urban spatial structure represents a complex nexus of centralising and decentralising forces at different scales with respect to different groups of people acting at different times in different places. The city has become more complicated thanks to these new innovations, rather than less, and our abilities to make sense of these changes in theoretical and scientific terms have not kept up"*. The Mobile Landscapes project shows how to take advantage of the very tools that have complicated urban life and turn them around in order to understand it better. It offers an opportunity to understand the mutating complexity of the contemporary city. Its focus on temporal, rather than spatial patterns, suggests a possible new paradigm for urban analysis: *"Dynamics of course represent the key to all of this. As architects and planners and urban theorists, we delight in approaching the city in terms of its morphology but morphology is not enough. It must be unpacked and the only way to unpack it is through dynamics"* (Batty, 2000).

10 Acknowledgements

The results reported in this paper are part of a broader research effort on the use of new technologies to describe cities. We are indebted to many people at the Massachusetts Institute of Technology for providing an extremely stimulating research environment and at the Universities of Cambridge, UK, and Siena, Italy, for their generous feedback. In particular, we would like to thank Nick Baker, Joseph Ferreira, Hiroshi Ishii, William Mitchell, Janet Owers, Paul Richens, Enzo Tiezzi, George Stiny, and Lawrence Vale. Of course, any shortcomings are our sole responsibility.

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