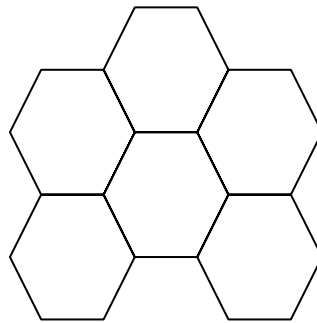


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MATEOS, PABLO (2004) "Mobile phones: The new (cellular) geography", unpublished MSc dissertation, University of Leicester.

MOBILE PHONES: THE NEW (CELLULAR) GEOGRAPHY



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24th September, 2004

Word Count: 14,934

ABSTRACT

This dissertation evaluates and proposes the application of mobile phone location as a new and very appropriate data collection methodology to analyse urban mobility in contemporary cities. The standpoint of this work is that traditional urban techniques currently available to measure and represent the new conceptions of contemporary cities are highly inadequate to embrace the new spatiality of the 'network society', or the 'space of flows'. The research starts with a theoretical review of such conceptions of contemporary cities and primary role of mobility as the major structuring element of a discontinuous space, rather than the traditional concept of a bounded and continuous space. Then an evaluation of the conventional tools available to urban geographers, geodemographers, and transportation researchers to measure mobility is presented. Highlighting the enormous gap between their conception of space and the one previously exposed. After making a case for the need of new technologies to tackle the complex spatio-temporal relationships that mobility allows in contemporary societies, mobile phone location is presented as one of those potential methodologies. A thorough analysis of mobile phone location technology is offered from different angles; its societal context, location services, new location uses and trends, methods of location, models for mobile objects, and the issues it raises on personal privacy. The research methodology then draws upon some of the major elements that will determine the success of this technology as a spatio-temporal coordinate system. The main aspect being location and temporal accuracy, spatial and temporal resolution and coverage, the automation of the monitoring process, and the visualisation of the resulting flows. Several mobile phone location tests were carried out to empirically evaluate some of these major elements at different scales, with varying results that are analysed and discussed in the light of the research questions. The most appropriate scale of analysis of this methodology is set to be that reflecting inter-urban mobility, as opposed to intra-urban flows. Finally, the main findings are summarized and some proposals for further research suggested with the aim to spark contributions in this direction and to try to avoid other researchers some of the problems and limitations that constrained the research presented here.

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1) INTRODUCTION

The title of this dissertation intends to be a homage to the book ‘Postcodes: the new geography’ (Raper et al, 1992) that marked a change of era in human geography, when postcodes expanded beyond its postal origins and became a new method to geocode socioeconomic information. Today, 12 years after the publication of this book, very few people think of postcodes merely as a postal delivery system, but instead as a type of geographic classification, and as an indication of location used in everyday life conversations.

This research is based on the premise that a similar parallelism can already be established between postcodes and mobile phones. As this dissertation will try to explain, mobile phones have become part of everyday life and have already surpassed its original purpose as an individual communication system. One of its technological side-effects is mobile phone location, that together with individual identification of its user, provides a new methodology that presents both an immense potential as well as serious challenges.

This dissertation evaluates and proposes the use of this new methodology to analyse urban mobility, based on the spatio-temporal analysis of large sets of mobile phone personal location information. Its main objective is to evaluate the suitability of this technology as a new methodology to understand urban mobility in contemporary cities.

The research questions are: How can the complex mobility flows of contemporary societies be monitored and represented? Does the high penetration of mobile phones in western societies justify its use as a proxy of mobility in such settings? What is the geographical accuracy of mobile phone location and what are its determinants? What are the best geographical scales of its application? Does it require new data models to represent spatio-temporal relations? What data privacy issues are involved with the usage of mobile phone location data in geography?

These questions have been tackled through the different chapters and sections in which the dissertation is structure, and not necessarily all in the methodological chapters.

Since the aim of the research is to introduce the use of a new methodology, the whole dissertation is set to that purpose.

The next chapter (2) contains two sections; the first exposes the contemporary conceptions of cities and the role of mobility as its major structuring component, while the second reviews the inadequacy of the traditional tools to measure such concept of mobility from the fields of population geography, geodemographics, and transportation. Chapter 3 offers an in-depth description and analysis of the technology of mobile phone location from different angles; its societal context, location services, new location uses and trends, methods of location, models for mobile objects, and privacy issues. This chapter sets the proposed technology in a broader theoretical context, and tries to review all the different aspects related with its use that are related to the research questions.

Chapter 4 describes the methodology carried out in the research, justifying the research techniques selected, explaining the problems encountered, and specifying the different steps taken in the three different mobile phone location tests finally proposed. Chapter 5 presents the results of those three tests, analysing in detail their outcomes and setting them in the theoretical context. Chapter 6 offers a condensed summary and brief discussion of those findings and some proposals for further research.

2) THEORETICAL JUSTIFICATION

2.1) The Mobile Society

This section will review the current urban debate on contemporary cities, in order to justify the selection of the dissertation's topic as an innovative methodology to understand current socio-spatial processes.

2.1.1) Understanding and Representing Contemporary Cities

More than half of the world's population live today in urban areas, and the 'urban lifestyle' predominates most of the human landscapes, in a way that the traditional distinction between urban and rural worlds has almost blurred (Johnston, 2000). If urbanization is seen as the normal spatial settlement of humans, does it still make sense to carry on talking about cities? According to Borja & Castells (1997), three major macro-processes seem to converge and make cities disappear as specific places of relationship between space and society; globalization, informationalization and the diffusion of urbanism.

In the last fifteen years, urban theory has moved a considerable way towards recognizing the varied and plural nature of urban life, acknowledging the inadequacy of one positionality on the city (Amin and Thrift, 2002). Cities are no longer seen as a bounded space around a single centre, as an independent organic structure with well-defined borders, nor as an integrated system following specific rules within an 'outside world'. Instead, cities are today perceived as; nodes in a space of flows (Castells, 1989), the relative space of the multiplex city vs. the uniplex city, as a result of *splintering urbanism* (Graham and Marvin, 2001), as a place of mobility, flow and everyday practices (Amin and Thrift, 2002). These and other authors, no longer see cities as spaces of fixity, where order should be sought, but instead as an amalgamation of changing flows, a station in networks of distant socioeconomic relationships, a relative space of complexity. Amin and Thrift summarize well this momentum in contemporary cities theory:

The city's boundaries have become far too permeable and stretched, both geographically and socially, for it to be theorized as a whole. The city has no completeness, no centre, no fixed parts. Instead, it is an amalgam of often disjointed processes and social heterogeneity, a place of near and far connections, a concatenation of rhythms; always edging in new directions. This is the aspect that needs to be captured and explained, without any corresponding desire to reduce the varied phenomena to any essence or systemic integrity. (Amin and Thrift, 2002, 8)

Despite a general consensus in this major turn on the conception of contemporary cities, there are conflicting theories about how contemporary cities should be understood and represented. This dissertation will not dig any deeper in the current urban debate, but instead will try to summarize the major common elements in the new concepts of contemporary cities, proposing a new methodology to represent such elements. There is a need for finding new representations of cities and but it is acknowledged that the right tools to do it have not been available. As Sudjic summarises it; 'It is true that in its new incarnation, the diffuse, sprawling, and endlessly mobile world metropolis is fundamentally different from the city as we have known it.... But the equipment we have for making sense of what is happening to our cities has lagged far behind these changes' (Sudjic, 1992, cited in (Amin and Thrift, 2002, 3).

2.1.2) Global Complexity and Relative Time-Space

As it has been mentioned above, urbanization and cities can no longer be studied in isolation from other socioeconomic macro-processes, the major one being the slippery concept of globalization, which will be briefly discussed here. Urry (2003) proposes a theory of *global complexity* as a complementary view to understand the globalization paradigm, based on what Rifkin calls "new physics". This theory is based upon the concept that time and space are not to be regarded as containers of phenomena (Newtonian absolute time), but rather all physical and social entities are constituted through time and through space (relative time) (Rifkin 2000, cited in Thrift 1996). This aspect of a change in the conception of time-space from an absolute to a relative one, will be tackled later on when analysing new data models for GIS (Geographic Information Systems).

The global space is comprised of flows and *mobilities*, of people, objects, and information along various global ‘scapes’, where the significance of the ‘relative’- as opposed to the ‘absolute’- location of a particular social group, or city, is in relationship to these multiple spaces (Urry, 2003). He adds that in these global ‘scapes’, information and transportation rich ‘tunnels’ can compress the distances of time and space between some places while enlarging those between others, creating ‘diverse networked time-space paths’. This concept fits well with the views developed in the 1970s and early 1980s within Time Geography, which will be mentioned later in section 3.5.

But this new conception of global complexity cannot be understood under a traditional view of space separated from time. ‘There is little sense in making distinctions between time and space – there is only *time-space*. Mobility takes up both time and space’ (Thrift, 1996, 285). This joint concept has been excellently experimented within the urban planning realm by a team of architects lead by Winy Maas (2003) that for example showed how Manhattan would look under “desired mobility” parameters. They play with the non-linear relationship of ‘real space Manhattan’ and ‘real time Manhattan’, which create ‘folds in space-time continuity, so that in order to save time space has to be boosted’ (Maas, 2003, 255).

These views of global complexity and relative time-space, will serve as a base to approach the understanding and representation of contemporary cities hereinafter.

2.1.3) Space of Mobility

‘In contemporary societies mobility has become the primary activity of existence’
(Prato and Trivero, 1985, cited in (Thrift, 1996, 286)).

The invention of the metropolis has been, from its very beginning even in the Middle Ages, related to the question of mobility (Cohen, 2003). Cities have served as exchange points (markets), and as trade and industry flourished through them they attracted migration. Their growth has always been conditioned by the technologies of transportation available at each time to move within them. The result of this continuous expansion as mobility possibilities increase, is the phenomenon of urban sprawl (Batty, 2003), or splintering urbanism (Graham and Marvin, 2001). Mobility is such an inseparable part of contemporary society that one of the key aspects in which each city

differs from the rest is the way in which its mobility is organized and facilitated (Verheyen, 2003).

Thrift (1996) builds a case for the apparent primacy of mobility in cities, based on the work of several postmodernist philosophers. Of interest to this dissertation is his emphasis on the role of speed, which according to Virilio ‘alters the nature of time and narrative, making everyone a passer-by, an alien or a missing person’ (Virilio, 1989, cited in (Thrift, 1996, 288)). Virilio argues that speed even drives place out of space so that ‘speed is a non-place and the users of transit-spaces, transit towns (like airports), are spectral-tenants for a few hours instead of years, their fleeting presence is in proportion to ... that of the speed of their voyage’ (cited in (Thrift, 1996, 288)). In other words, the higher the speed the ‘less presence’ of the individual and the ‘less place’ of the ‘in-between spaces’. Linked to this view of ephemeral presence and places, Thrift (1996) draws upon Deleuze’s work on nomadism. This concept is seen as “something that happens between, only temporarily occupying a space and imposing no fixed and sedentary boundaries, ...[with] [t]he nomadic subject traversing points of pure intensity in migratory fashion” (Thrift, 1996, 288). But true nomads, who are the most mobile form of society, do not require any infrastructure to move because their tempo is very slow (Verheyen, 2003). When fast mobility is required, then infrastructure allows to trade (travel) time for sections of space, at different speeds. Therefore, mobility in contemporary societies is a question of speed of movement, lying behind the no-places, the space in-between social activities. For Thrift (1996) this re-opens the debate about the definition of place:

What is place in this new ‘in-between’ world? ... permanently in a state of enunciation, between addresses, always deferred. Places are ‘stages of intensity’, traces of movement, speed and circulation (Thrift, 1996), 289)

As a result of all these implications mobility is an extremely problematic concept to grasp and communicate, and therefore demands a profound change in the type of representation of, in Thrift’s own words, ‘the elliptical world in which we now live’, beyond that of standard writing (Thrift, 1996, 282). Sheller (2004) reviews a number of metaphors that have been lately used to describe and understand cities as social processes, in a world perceived to be increasingly ‘disorganised’ and ‘complex’. Such

metaphors include; the ‘space of flows’ (Castells, 1996), ‘global fluids’ (Urry, 2003), ‘fluidity’ or ‘liquidity’ nature (Bauman, 2000), the ‘liquefaction’ of the urban structure (Graham and Marvin, 2001), or a ‘social gel’ (White, 1992).



Figure 2.1 Topography of a ball of scrap wire ‘... and that the entire world is just a tangled ball because people have all rolled up their horizon with themselves included – all one big ball’ (Spoerri, 1995; cited in Smith, 2003a, 565)

‘Yet, in contrast to the mathematical precision of much network analysis, many of these suggestive metaphorical statements about the contemporary condition lack empirical specification of how such an unstructured structure might work. What mechanisms animate liquid sociality? What agencies are at work to make social connections gel or evaporate? (Sheller 2004, 47). This dissertation tries to move beyond those metaphors and representations (see Figure 2.1), and explore a much more empirical methodology to measure and represent contemporary cities, through measuring mobility as a way to understand its ‘liquid’ or ‘fluid’ structure.

2.2. Sources of mobility data

This section will review the areas of research and methodologies currently available to investigate the problem of understanding mobility in contemporary societies from a geographical point of view. The different approaches to this problem will be explained briefly, and the research gaps in these traditional understandings of mobility will be identified. These areas of research are; Population/ Census Geography, Geodemographics, and Transportation, and will be discussed here in relation to one of its main applications, the need to estimate local demand for public or private services (Webber and Longley, 2003), in this case the mobility of such demand.

2.2.1) Population/ Census Geography

The main source of data for any social scientist interested in research related to demographics has historically been the population census that most countries in the world conduct on a regular basis (generally every 10 years) (Dale, et al., 2000). The most important characteristics of the censuses are; that they represent the largest detailed data collection exercise providing complete coverage of the population (Martin, 1993), that all citizens have a legal obligation to answer the census questions (as opposed to most other non-mandatory national surveys), and that the government is also required to protect the data supplied by the public and to ensure that confidentiality pledges are not broken (Dale, et al., 2000).

In the UK, the sections of the Census that most closely deal with research on population mobility are the *Migration Statistics* and the *Workplace Statistics* (Rees, et al., 2002; Rees, 1997; Stillwell and Duke-Williams, 2003). The workplace statistics variables of interest in understanding mobility are; the journey from residence to workplace (geographical locations), the length of this journey, and the mode of transportation used. These datasets contain very rich information that is not available from any other source of socio-economic data in the UK in terms of geographical coverage and spatial disaggregation (such as the National Travel Survey, or the London Transport Surveys). Nevertheless, according to Cole et al. (2002) the Census Workplace Statistics present a number of inconveniences. It only covered a 10% sample of total census respondents in 1981 and in 1991 (2001 should be 100%), and of this sample, 10% of individuals could

not be given an identifiable workplace. Furthermore, the geographical location of workplaces is not very accurate and sometimes results in a number of anomalous journeys when mode of transport is considered (Cole, et al., 2002).

In general the Census of population is not an appropriate data source to study mobility in contemporary societies. Amongst the major drawbacks would be that it is only updated every 10 years, its basic unit of measurement is the household, the physical location assigned to society variables is the place of residence (except for a few questions on workplace), and it presents results aggregated by area-to-area mobility flows. Furthermore, the problem of a 10% error rate in trying to accurately assign every worker to a single workplace (i.e. 2.3 million people), exposes a traditional conception of work underpinning the Census questions that do not acknowledge the reality of the post-fordist production system (flexible/multiple jobs, work-from-home, mobile workers, etc). Even Cole et al. (2002) recognize that 'as with many apparently simple census questions, it is sometimes difficult to deal flexibly with the complicated reality of many respondents' lives' (Cole, et al., 2002), 271). It is this point that best illustrates the inadequacy of traditional sources of socioeconomic data to understand mobility in contemporary societies, because the majority of them do not acknowledge that 'time patterns in the city are being stretched and reconfigured beyond the rigid routines of work, commuting and home time characteristic of the classic industrial metropolis' (Graham and Marvin 2001, 204).

2.2.2) Geodemographics

The term geodemographics can be defined as 'the study of population types and their dynamics as they vary by geographical area' (Birkin and Clarke, 1998, 88). Although in Geodemographics, like in the Census of population, socio-economic information about the population is typically assigned to their place of residence, recent efforts have been made to obtain the lifestyle characteristics of people while at different geographical locations, such as their workplaces, or places of consumption/ entertainment. These efforts follow an urgent marketing need to know not only where people live (sleep), but also where they actually are during the day (Dugmore, 2004).

Two examples of these new developments are *WorkPrizm* a U.S. product to classify working population at their workplaces (Claritas, 2004a), and *Cuende Geomex* a

Spanish tool to measure population daily flow and lifestyle through city streets at address level (Cuende Infometrics, 2004). They reflect the fundamental change of focus in the geodemographics sector, from the until recently fashionable, “you are where you live” (Claritas, 2004b), to the motto of *Cuende Infometrics*; ‘The most important thing in this world isn’t to know where you are, but where you go’ (Cuende Infometrics, 2004).

This trend is also confirmed by Keith Dugmore, a UK geodemographics expert, who recently stated that the geodemographics sector is in urgent need of research into new sources of population information outside the place of residence. Furthermore, the geodemographics effort trying to track mobile customers, currently refers not only to highly spatially mobile target groups, but also to individuals constantly changing their consumer identity and location preferences (Gordon and Valentine, 2000).

These efforts to classify total populations outside their place of residence demonstrate the increasing importance of mobility in contemporary societies, and the need for new techniques to measure and understand mobility for a variety of purposes.

2.2.3) Transportation Research

As opposed to the Census and Geodemographics studies, Transportation Research does not typically intend to cover total populations (at national or regional level). Instead, it focuses only on the specific potential users of certain transportation networks (public or private) usually in a single urban metropolitan area. This area of mobility research has traditionally been comprised of civil engineers and urban planners (Daniels and Warnes, 1980), interested in finding more accurate models to estimate transportation *throughput* (Miller, 2004a). In order to do this they need to forecast travel demand and specific traffic patterns in cities. Researchers in space-time behaviour analysis are typically interested in understanding the different needs for travel of individuals, their time and financial constraints (Bhat and Koppelman, 1999), the location and characteristics of their origins and destinations (Srinivasan, 2002), how different trips are chained (Golob, 2000), and the modes of transport chosen. A wide variety of transportation models to analyse and predict space-time behaviour have been produced over several decades, and can be grouped into; constraints-based models, utility-maximizing models, and computational process models (Timmermans, et al., 2002).

All these transportation modelling efforts are based on travel demand datasets that have historically come from travel surveys carried out by metropolitan authorities. In recent years the introduction of global positioning systems (GPS) in the measurement of individual travel has substantially improved the quality of these datasets, not only in terms of geographical accuracy, but also as a support tool to help citizens re-call their trip-purposes (Edmonson, 2001) (Murakami and Wagner, 1999) (Stopher and Wilmot, 2000) (Wolf, et al., 2001) (Wolf, et al., 2004).

The use of Geographical Information Systems (GIS) in Transportation has also been a key technological improvement that has experienced a rapid and steady growth in the last 15 years, maturing into an independent field of research widely known as GIS-T (Waters, 1999). Of interest here, one of the uses of GIS-T in space-time behaviour analyses has lately focused on the measurement and modelling of individual accessibility, understood as a person's physical reach in space and time through movement (Miller, 2004b). From the Geography perspective, accessibility has been specially studied in relative terms, comparing different social groups' space-time possibilities, in order to map urban isolation (Couclelis and Getis, 2000) (Kwan and Weber, 2003) (Miller, 2004b) (O'Sullivan, et al., 2000) (Weber and Kwan, 2002). The concept of accessibility is closely linked with that of mobility, since it basically measures the movement possibilities that an individual has at certain points in time and space. Miller (2004b) defines a second concept of *extensibility*, which extends the idea of accessibility, referring to the ability to project an individual's presence beyond the physical location in space and time (e.g. through a telephone conversation, an e-mail message, etc).

These different lines of research, that have been grouped here in a broad Transportation Research field, all primarily depend on the availability of accurate and timely movement data about individuals in a urban context. As it has been mentioned above, the introduction of new tracking technologies, such as GPS, has substantially improved the accuracy of these studies, reducing the survey cost and participants' efforts (Edmonson, 2001). Nevertheless, the use of GPS presents several drawbacks, the main ones being: its unavailability or inaccuracy inside or close to buildings, the limited number of individuals to be simultaneously monitored and the duration of the study, due

to the expensive cost of the GPS units and database complexity (e.g. a maximum of 100 individuals in the study by Murakami & Wagner (1999), the short length of the survey duration, and the inconveniences caused to individuals carrying a GPS (it is a bulky device, they have to make sure they switch it on and off and charge the batteries) which also influences the user's perception of being 'spied' increasing the risk of its selective switch-off. Furthermore, in many studies is not the user who is individually tracked but their vehicles, based on the assumption that the individual does not share his/her car with other drivers and that trips done using other modes of transportation are irrelevant (Wolf, et al., 2004).

Of all these GPS drawbacks in tracking travellers, the most important for this dissertation is the restriction in the number of individuals that can be simultaneously tracked and the duration of time they are monitored. Wolf, et al. (2004) describe a significant improvement in these restrictions over the past years, with studies increasing in sample size and duration - from dozens to hundreds of study participants and from a couple of days to months and years in length.

Two other technologies that overcome some of these drawbacks, complementing or even substituting GPS, have been recently tested to track individual movements in a transportation research context; mobile phone location and RF-ID (Radio Frequency Identification) (Asakura and Hato, 2001) (Hato and Asakura, 2001). The former will be the main theme of the rest of this dissertation, and the latter will be briefly mentioned in some of the sections.

2.2.4) The need for a new source of mobility data

The previous sections have exposed some of the current sources of mobility data available, their problems and limitations, and their main uses in three major fields connected to Geography and GIS.

From this review it can be concluded that the techniques and sources of data currently available to understand mobility are not at all adequate to grasp the rapid changing pace of contemporary societies and cities, as it was described in section 2.1. The major problems of these sources of data and methodologies could be summarized as follows:

-
- The dominance of space-centred measures vs. people-based measures (Miller, 2004b), providing data that is typically based or aggregated at the place of residence.
 - The household being the basic unit of analysis, vs. analysing individual mobility
 - Major restrictions either in the number of individuals and geographical extent surveyed (Transportation Research), or in the frequency of their update (Census and Geodemographics)
 - Survey techniques are highly expensive, manually intensive, time-consuming and error-prone.
 - Low geographical accuracy of the measures of mobility (except for GPS tracking that instead offers poor urban reliability)
 - Based on a preconceived idea of social structural spatio-temporal patterns that do not any longer fit the complex reality of individual lives (Cole, et al., 2002), because they do not acknowledge the new movement patterns resulting from profound changes in household composition and the labour market (Longley, 2003)

Therefore, new mobility measurement techniques that overcome these limitations and offer new insights into the continuously changing reality of the so-called mobile contemporary society are urgently needed. This dissertation contends that mobile phone location is a technology that not only meets these requirements, but also offers radically new possibilities in the way ‘mobile society’ can be analysed.

3) MOBILE PHONE LOCATION AND ITS REPRESENTATIONS

3.1) Society and Mobile phones

During the last 10 years, mobile phones have become an integral part of contemporary societies, not only in developed countries, but also in the so-called developing countries, where in many occasions it is the only type of telecommunication technology available to its citizens (Agar, 2003). Today the number of mobile phones worldwide is 1.2 billion units, and in many countries they have reached a penetration of over 70% of total adult population widely surpassing the number of fixed telephone lines.

This phenomenal growth is signalling the inherent essence of the mobile phone versus the fixed telephone; the mobile phone identifies and communicates the person who owns it, while the fixed telephone line communicates the household or the company (Cairncross, 2001). It is this personal use and individual identification, together with the ubiquitous possibilities of nearly anytime/anywhere one-to-one communication that has made mobile phones so popular. Their diffusion has been much faster than any other mass technology in the past, to the point of starting to be considered today as an 'extension of the body' (Townsend, 2000).

These are the pivotal points that justify the use of mobile phones as the location technology for this dissertation; their high penetration in society, their accepted status as an always-on wearable device, and the individual identification of users. Other societal aspects of the mobile phone boom will not be covered here (see (Lacohée, et al., 2003) for a review), nor its technical evolution and future developments. Nevertheless, additional research would be needed to identify the social groups that lie in the remaining proportion of society that is not using mobile phones, and establish the major factors in their decision, since they would not be covered by the methodology analysed here (e.g. see (Osman, et al., 2003)).

3.2) Mobile Phone Location

Mobile phone operators need to know the geographic location of each mobile phone device in the network in order to be able to route calls to and from them, and to seamlessly transfer a phone conversation from one base station to a closer one as the user is moving while talking. This technical need was transformed into a commercial opportunity to increase the *Average Revenue Per User* (ARPU) (Adams, et al., 2003), through what are known as 'Location Based Services' (LBS).

LBS are all those services that use the location information of a mobile device to provide a user with location-aware applications (Fisher and Dobson, 2003). Such location information can be provided by the network operator, the mobile phone device, or a combination of both. The type of LBS applications proposed were very broad and creative and raised many expectations in the general public (Schofield, 2004). Nevertheless LBS failed to deliver its promises at the turn of the century, and its huge forecasted market potential did not come to reality basically because the users have not found any true value in the few service options available (Zetie, 2004). However these early services have been very restricted due to the poor location accuracy available, and the limited capabilities of both the handheld hardware (screen size/quality, processing power, and storage capacity) and the network data transfer speeds and bandwidth (Mountain and Raper, 2001). The location accuracy issue is directly related to this dissertation topic and will be analysed in section 3.4 and in chapter 5, but hereinafter only the location aspect of the much broader 'LBS field' will be considered in the analysis (the 'L' in LBS).

Despite the initial commercial failure of LBS, new legislation recently introduced by U.S. and European authorities requiring mobile phone operators to provide an accurate location for calls to emergency services, have acted as a catalyst for increased commercial support of LBS in the last 2-3 years (Chen, 2004a). Worldwide revenue from LBS is now expected to increase to more than USD \$3.6 billion ('000s millions) by 2010, from \$500 million today (Chen, 2004a). Those legal requirements and their implications for location accuracy demands will be discussed in the next section (3.3). The second characteristic of this LBS 'revival' is that the most successful applications

are not those that offer location-aware contents to the mobile device user, but instead, those that provide the user's geographical location to a third party, together with some other value added services (e.g. tracking children, travelling employees, or vehicle fleets (Zetie, 2004). These services have raised new privacy challenges that will be briefly exposed in section 3.6, at the same time that have allowed this research the use of a tool to track third-party mobile phones location, which is at the core of this dissertation methodology section.

3.3) New location uses and requirements

The automatic location of persons or mobile objects is currently a much broader research field and commercial market than the now traditional LBS for mobile phones. As computers become ever more ubiquitous and multi-functional, mobile computing devices 'need to know' its geographical location in order to perform certain functions (Costa-Requena, et al., 2001). This broad field of ubiquitous computer devices is generally referred to as 'wireless computing', and the devices that are aware of or provide its location (e.g. GPS, mobile phones, RF-ID tags, etc) have been termed 'Personal Location Devices' (PLD) when they refer to the person that is using them (Fisher and Dobson, 2003). Therefore, the discussion about mobile phone location presented here should be placed within this much wider subject of wireless computer device location, which has been reduced in this dissertation to mobile phone location for simplicity due to its enormous popularity.

A major distinction must be made between applications where the location information is only known by the PLD device itself, its 'end-user', or the network operator, and those in which this information is passed onto a third-party. A third-party refers here to an organisation or person who requests the location information of a PLD, being a different entity from either the user of the PLD (1st party) or the network/technical operator of the PLD (2nd party) (Fisher and Dobson, 2003). The current debate and new thrust of mobile phone location applications in the last 2-3 years has been particularly centred in the second group.

The situations in which society is ready to relinquish some individual privacy for a greater benefit are typically those where life is at risk, or justice is to be made. The privacy issues of disclosing such information are briefly exposed in section 3.6. Here, the main new uses of such disclosures will be summarized, since they are currently shaping the new location requirements and are providing new scenarios for future research in this dissertation's topic area.

3.3.1) Emergency Services

In situations where life is at risk, the most important strand of new location applications fall within the emergency services arena. The dispatchers of emergency-response organisations recognized the growing problem of not being able to locate calls from mobile phones, which in many countries account for over 50% of total calls to emergency services (Salmon, 2003). The caller is usually not able to provide his/her location accurately to send a rapid response, especially under a panic situation or when outside the area of his/her daily wanderings (Hunt, 2004).

In the USA a set of legislation known as 'e-911' (for 'enhanced 911', the federal emergency number) was approved by the Federal Communications Commission (FCC) as early as 1996, requiring all the wireless communication operators to provide the automatic location information (ALI) of callers to 911 emergency services (Federal Communications Commission, 2004). The initiative was to be rolled out in two phases; 'Phase I' required call operators to report the telephone number of a wireless 911 caller and the location of the antenna where the call has originated (a location method known as Cell-ID). 'Phase II' required wireless operators to provide far more precise location information, within 50 to 100 meters in most cases, but that can be increased to 150 or even 300 meters for a small proportion of calls¹. Due to the technical difficulties of providing such location accuracy across the US territory (specially in low populated rural areas), the FCC has delayed the roll-out (Salmon, 2003). Phase I was finally achieved by 2001, and 'Phase II' is to be developed between then and December 31st, 2005 (Federal Communications Commission, 2004). Each operator has had to choose

¹ For network-based solutions — 100 metres for 67% of calls, and 300 metres for 95% of calls,
For handset-based solutions — 50 metres for 67% of calls, and 150 metres for 95% of calls.
(Salmon, 2003)

one of the two technological broad methodologies to provide ALI; ‘network-based solutions’, where the network calculates the location of the caller, or ‘handset-based solutions’, where the location is provided by the actual handset (requiring GPS-enabled phones). The FCC has already fined several operators with millions of dollars for failing to meet requirements (Weaver, 2003).

The importance of the e-911 initiative lies in the fact that, based on the legal pressure faced by mobile phone operators, the wireless location market has been exhausting all the technical possibilities that were financially feasible to provide an accurate ALI, speeding up dramatically the implementation of true valuable LBS, as a side-effect (Branscombe, 2003). This effect has expanded outside the US, since operators have anticipated similar governmental initiatives in different countries, and in some cases ALI technology has been rapidly adopted as network standards have evolved (see next section 3.4).

Similar but later efforts have been introduced in the European Union under the e-112 directive (European Commission, 2001), proposed in 2001 and finally approved in July 2003 (Branscombe, 2003), whose benefits are just starting to be realized by the emergency services sector in some EU countries (Hunt, 2004).

3.3.2) Terrorism and Crime prevention

Other examples of the new uses of mobile phone location information by third parties that have already started to be accepted by society are related to the numerous recent measures to tackle terrorism or crime. Mobile phone location information is already being used by the police to track offenders, either in chases or as evidence for trials. Summers (2003) reports 6 different trials where mobile phone location evidence proved decisive in the conviction of murderers between 2002 and 2003, depicting this technology as ‘the new fingerprints’.

The value of this technology for police has been definitely proved during the Madrid commuter trains terrorist bombings on March 11th, in which mobile phones played a major role in both activating the bombs and capturing the terrorists. The terrorists used a mobile phone in each of the 11 bombs to activate them remotely, but police used an unexploded one to trace the set of 200 SIM cards that the terrorists and their supporters

had bought. Through them, they quickly identified all the people involved, their relationships (through phone calls and SMS), and most importantly traced their locations before and after the attack up to the point of their capture (El Pais, 2004).

But the way that mobile phone location technology currently works can only partially help the police authorities, not only because of the location accuracy problems already mentioned, but most important due to the ephemeral nature of the location data. Unfortunately, those ‘new fingerprints’ are not permanently stored by the network operators unless a phone call is made, an SMS sent, or the handset is switched on or off (transaction location information), and even so it seems that the data is only kept until certain billing cycles are completed. Therefore, the ‘new fingerprints’ are being constantly erased as they are recorded, a fact that the police authorities are already trying to change. In the UK, the Home Office has proposed a requirement for mobile phone operators to keep location information for 12 months and SMS for 6 months (Mathieson, 2003).

Despite the current shortcomings of mobile phone location as ‘the new fingerprints’, since mobile phones form today an integral part of society accompanying over 70% of us wherever we go, they have an enormous retrospective value in understanding how complex mass events have developed involving the mobility and linkages of thousands of people. It will not be long until authorities require not only actual mobile phone transaction location information to be stored but also random ‘time-location stamps’ of all switched on devices at certain temporal intervals in certain places. This fact would result in a tremendous potential for the type of geographical analyses this dissertation will propose, taking into account the individual privacy issues that will be discussed in section 3.6.

3.4) Mobile Phone Location Accuracy

Having set a case for the need of accurate mobile phone location technologies, this section will briefly review the current positioning methods available and their accuracy estimates, which will then be tested in the methodology section.

There are several approaches to finding the PLDs user's location employing various technologies and resulting in several geographical accuracies. Until recently, a distinction in the positioning technology of a PLD would clearly differentiate the type of device and its market sector (e.g. mobile phone, GPS or RF-ID tag). As these technologies have been miniaturized they are being combined in hybrid solutions that use more than one of these location methods to calculate its position (such as GPS-enabled phones)². Nevertheless, due to the majority of PLDs still having a 'stand-alone' positioning method, and the majority of PLDs used being mobile phones (in a traditional sense), network-based location methods only will be explained in this dissertation.

Mobile phone location methods (until GPS-enabled phones recently appeared) rely on the way operators structure the cellular network of transmitters for finding phones in their service territory and route calls to them. This basic type of phone positioning is called *Cell-ID* location (Cell Identification), a method that requires little investment but provides poor accuracy since cells vary greatly in size, especially outside urban areas (Spinney, 2003). Accuracy of Cell-ID location depends on the size of the cell where the user is located (the greater the cell size, the less accurate the location estimate is), and cell-size being dependent itself on several factors; the density of transmitters that an operator has in an area, the power of these transmitters, the height of the mast, and the obstacles around the mast (buildings, trees, topography). As a result, the accuracy can vary from 500 metres to over 5 km (see chapter 5).

A variation of Cell-ID methodology has been denominated Cell-ID++, which combines basic Cell-ID positioning, with Timing Advance (TA), and Network Measurement Results (NMR). TA corresponds to a distance estimate from the base station to the

² Some of the manufactures of GPS-enabled phones being ; Benefon, Garmin, Motorola,

handset based on timings, while NMR measures the power of the signal received by the mobile phone from the adjacent base stations (Faggion and Trocheris, 2003). Cell-ID++ just reduces the length of the radius around a base station where the mobile phone is likely to be located situating it within a certain perimeter around it.

In order to improve location accuracy beyond Cell-ID solutions many different methods have been proposed. The methods that will be explained are; 'Angle of Arrival' (AOA), 'Enhanced Observed Time Difference' (E-OTD), and 'Time Difference of Arrival' (TDOA). New hybrid solutions include methods that combines both network and handset based location calculation, of which Assisted-GPS (A-GPS) method is the most promising and accurate one (Zhao, 2002).

The 'Angle of Arrival' (AOA) method requires a minimum of two base stations to determine the angle of arrival (also called direction of arrival) of the mobile phone signal, and the network then works out the handset location by triangulation (Figure 3.1-a). This method is difficult to implement because directional antennas or antenna arrays are required, and servers placed at the base stations should be able to compute and transmit to other base stations the directional information of each handset (Zhao, 2002).

'Enhanced Observed Time Difference' (E-OTD), or also called 'Time of Arrival' (TOA) (Zhao, 2002), measures the time difference between signals from three or more base stations under the handset coverage and obtains the position by calculating the distance from each station (Figure 3.1-b). A similar method is used by GPS to compute position from three satellite signals (Zhao, 2002). This technology requires several conditions to occur across a whole network; the locations of base stations must be precisely known, it must be made available to mobile receivers as frequent network traffic, both the network and the handset must be synchronized, and software tools for interpreting this information must be installed either on the phone itself (SIM card) or at the server. According to Mountain & Raper (2001) most of the networks did not provide these conditions (at that time), nor were the handsets ready, and even when all factors converge the accuracy is at best 200 m. in urban areas.

A different method that does not require time synchronization is 'Time Difference of Arrival' (TDOA) in which the mobile phone position is determined by the network's

servers based on trilateration, (Figure 3.1-c). This system uses time difference measurements rather than absolute time measurements, as E-OTD does, but instead of requiring time synchronization between the base stations and the handset, it does require a means to measure time differences very accurately. For example, a $1 \mu\text{s}$ timing error under this methodology would lead to a 300 m position error (Zhao, 2002). Therefore, this methodology again requires network modifications and expensive infrastructure investment. Even with the right precise clocks TDOA accuracy is unlikely to exceed 50 metres under any conditions (Mountain and Raper, 2001).

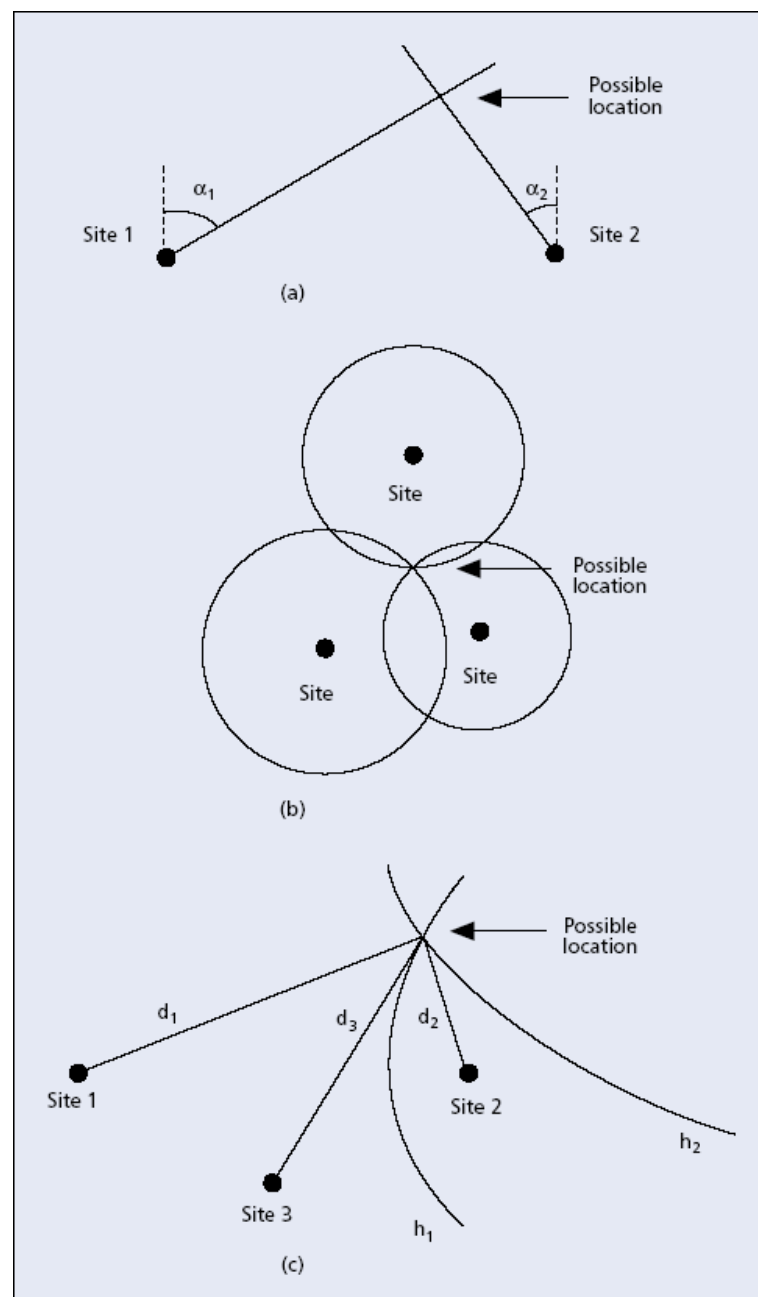


Figure 3.1: Position determination methods: a) Angle Of Arrival (AOA); b) Enhanced Observed Time Distance (E-OTD); c) Time Difference Of Arrival. Source: Zhao (2002) p.109

Finally, a totally different type of positioning technique is ‘Assisted-GPS’ (A-GPS) which requires a GPS-enabled mobile phone. ‘A-GPS’ settings improve the performance of a stand-alone GPS by providing additional contextual information to the GPS-enabled handset coming from the nearby base stations (Faggion and Trocheris, 2003). This reduces the location errors caused by urban interferences to GPS signals, and provides a first location estimate during the long time of GPS ‘cold-start’ (30 seconds to several minutes) (Zhao, 2002). As a result, A-GPS location methodology is substantially more precise than any of the other solutions reviewed, and Zhao (2002, 115) recognizes that ‘an accuracy of under 20 m. is a very reasonable expectation in 67% of the calls’.

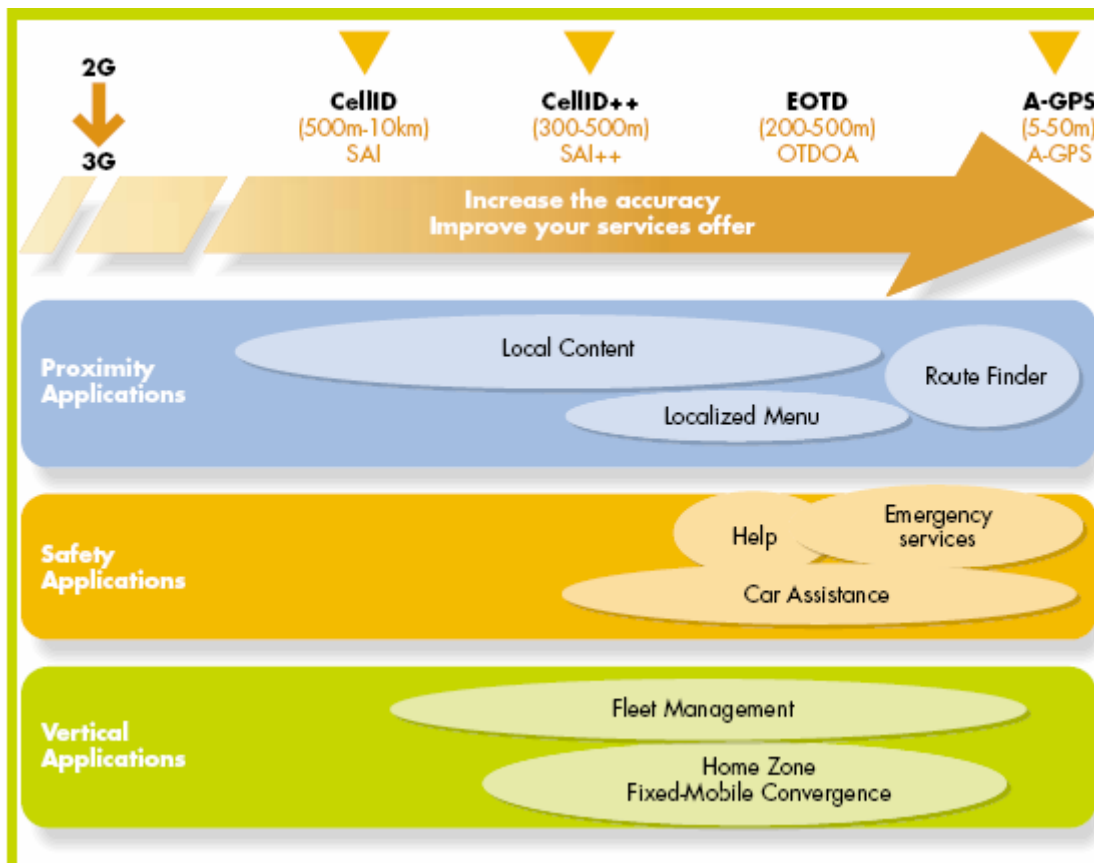


Figure 3.2: Positioning Methods for Different Applications

Source: Faggion & Trocheris (2004), 4

Furthermore, and as a consequence of the e-911 initiative in the US, mobile phone operators are finding it quicker and cheaper to convince mobile users to switch to GPS-enabled phones, rather than make more network investments in 1st or 2nd generation mobile phone technology (respectively CDMA and GSM) that will be soon replaced by

3rd generation standards (such as UMTS) (Federal Communications Commission, 2004). This trend, together with the fact that A-GPS is the most accurate and reliable method will mark the future developments of mobile phone location. However, A-GPS will not be considered for this dissertation since it requires the use of GPS-enabled mobile phones, which currently have a very low adoption rate by users³.

3.5) Mobile Object Models

The type of data collected by mobile phone location methods present specific characteristics that within the geographic information realm fall in the so-called 'moving objects' group. Such type of data requires an innovative approach to its representation and modelling, due to its spatio-temporal multidimensionality (Dykes and Mountain, 2003). This section will briefly review the issues involved with building appropriate data models for mobile phone location, its representation and analysis.

3.5.1) Representing and analysing moving objects

Raper (2000) argues that geo-representations faces a number of profound challenges to current methodologies based on two-dimensional 'timeless space' concepts, and states that new multidimensional approaches to digital geo-representation should be built. Langran (1992) was among the first to explore spatio-temporal knowledge representation, claiming the need for a unified spatial and temporal approach, rather than the reality of either space-based or temporal-based independent representations, although the majority of commercial GIS systems still remain wholly a-temporal in nature (Raper 2000).

Most of the research related to the construction of spatio-temporal GIS focus on the problem to represent, store, query, analyse, model and visualize changing objects in geographical space and build models of time (Langran 1992, Peuquet 1994, Mikula *et al* 1996, Christakos *et al* 2001, Aamodt 2000, Frank 1998). These data models and techniques originally proposed must be reviewed in the light of increasingly available massive volumes of spatially referenced data about discrete mobile objects, such as

³ Even though, the market is growing very rapidly, with the leading providers of this technology being SnapTrack, Alcatel, and Ericsson.

mobile phone location, which challenges current representations in terms of computer efficiency (Dykes and Mountain 2003).

There is a great potential to analyse this data in order to generate knowledge about moving objects, most specifically about individual persons' behaviour, in time and space (Dykes and Mountain 2003). In order to analyse large samples of individual mobile behaviour, new spatial analysis techniques are required to establish movement pattern of both individual and aggregated trajectories (of points) through different time-scales, and find evidence of clustering either in the spatial, temporal or attribute dimensions (Mountain, 2003).

Point pattern analysis is a well established area of research in GISc and other sciences, which aims to find spatial patterns in point data such as evidence of clustering (Imfeld, 2000). Nonetheless, most of the research in this area is concerned with either a-temporal representations, or a series of temporal snapshots of a static study area. In the former type of analysis of point pattern, the linkages between the same individual point (the changing object) throughout the different temporal snapshots is usually disregarded (Batty 2003), focussing instead on the identification of change in the overall pattern. Imfeld (2000) denounces a lack of consideration of time in overall point pattern analysis, and blames the lack of temporal development of GIS and the absence of established analysis methods.

Mountain and Raper (2001) propose a point-pattern analysis method called the Location Trends Extractor (LTE), suggesting that the key to summarising the spatio-temporal behaviour (and therefore finding patterns) lay in identifying breakpoints in the data, such as 'significant' spatial or temporal jumps, or sudden changes in speed or direction. These breakpoints can then be used to demarcate *episodes* in the user's position history, which each contain a relatively homogenous spatio-temporal period, such as a single car journey. The main focus of these researchers at the City University of London, in relation with this dissertation's topic, has been the development of visualization techniques, such as continuous point density surfaces (Mountain 2003, and 2001, Mountain and Raper 2001, Dykes and Mountain 2003).

Other authors have suggested to use exploratory approaches as more effective in finding the spatio-temporal pattern. Openshaw *et al* (1994) made a case for the use of map animation as a spatial analysis tool, based on the much earlier work of Tobler (1970).

‘The argument is that the use of video technology and the observation of data in ‘all its glory’ may afford a mechanism whereby it is far easier to ‘see’ patterns and processes by watching a movie than it is to model them using mathematics, or by observing similar processes in the real world’ (Openshaw *et al* 1994, 138).

3.5.2) Time Geography representations

Time geography, originally proposed by Törsten Hägerstrand and the Swedish geography school of Lund, is a powerful conceptual framework for understanding human spatial behaviour, in particular, constraints and tradeoffs in the allocation of limited time among activities in space and time (Thrift, 1978, 4). Time geography has enjoyed a resurgence since the 1990’s due to an improvement of the computational representation of basic time geographic entities, such as the space-time path and prism, using geographic information systems and related technologies (e.g., Forer 1998; Kwan and Lee 2003, Miller 1991), and the increasing availability and accuracy of personal location data through GPS and LBS technologies (Miller 2004a). Of specific interest here the *space-time path* traces the movement of an individual in space and time, and is represented by a line moving in the space-time cube (Thrift 1978).

Time Geography follows a representation of time in space that has been classified by Langran (1992) as the *space-time cube*, with two spatial and one temporal dimension. A different type of representation have been proposed by Dykes and Mountain (2003), as a $2-D + t$ representation that treats time as a separate variable. Other authors have picked up on the implementation of Time Geography within GIS in the late 1990’s following two different approaches to the 3-D space-time cube; the vector data model (eg. Miller 2004a) and the raster data model (eg. Forer 1998).

3.6) Privacy issues

What counts is not the barrier but the computer that tracks each person's position – licit or illicit – and effects a universal modulation (Deleuze, 1992, cited in Thrift, 1996, 291)

Mobile phone location has attracted a wide interest in the critical analysis of its challenges to individual privacy, since it allows a person's location to be known by other people. Due to the length limitations of this research it is impossible to cover the range of opinions and views thrown over the subject, but a few will be briefly mentioned here⁴.

The right to privacy in the handling of personal data is regulated in most of the countries by personal data protection legislation. These ensure that personal data should only be collected where necessary, should be only used for the purposes for which they were collected, should not be disclosed to another group or agency without some sort of consent, and should be securely stored (Curry, 1999). Of interest to this dissertation are the situations of disclosure to another group or agency (here named a third party), and the requirement of specific user consent.

As mentioned before in section 3.3, society has already deemed necessary to relinquish some individual privacy for a greater benefit from mobile phone location, typically in situations where life is at risk (emergency services), or justice is to be made (criminal evidence). Fisher and Dobson (2003) propose a typology of seven scenarios for the use of personal location information, and establish whether disclosure of such information to third parties will be very beneficial, and therefore should be legally permitted, and those in which it should not.

This dissertation proposes the use of mobile phone location technology as a proxy to understand mobility, and therefore would require the consent of mass groups of society in order to be truly representative. The approach should then be to ask the potential participants for their consent, ensuring the information is only used for the purpose of

⁴ For an extensive review see the following references; BBC News (2003a), (2003b) and (2004); Bird (2003); Bowcott (2004); Curry (1999); Dodge (2004); Dodge, et al. (2004); Doward (2003); Fisher & Dobson (2003); Mathieson (2003); Mathieson (2004); Millar (2003); Raper (2001); The Economist (2004b); The Guardian (2004a) and (2004b); and Woolnough (2004).

understanding urban mobility in aggregated ways. This is a similar scenario as with the information requested in the Census of population, in which all citizens are obliged to provide personal information that will be only disclosed in a spatially aggregated form (Dale, et al., 2000). Nevertheless, new legislation should regulate a ‘new right to privacy in a geocoded world’ (Curry, 1999), so that these beneficial uses are permitted and potential abuses prosecuted, before the technology is made ‘blind’ altogether, and its potential urban research benefits are lost.

4) RESEARCH METHODOLOGY

After having justified the theoretical validity behind the proposal of using mobile phone location as a proxy of mobility to understand contemporary cities, this section will present the research methodology employed in order to build up empirical evidence towards answering the research questions. The results derived from this methodology will then be presented and analysed in chapter 5, and furthered discussed in chapter 6.

The main objective of the methodology selected in this research is to illustrate through meaningful examples what would be the characteristics, limitations and potential uses of different datasets containing mobile phone location information for a wide group of users in a metropolitan area. The approach taken in this research is primarily focused on empirically analysing the features and shortfalls of these new personal location datasets, to determine the success factors that would allow this technology become a valid data collection method as a proxy of population mobility. As a result of this analysis, the benefits of this method and its challenges to be overcome will be presented, as well as a draft research agenda for the introduction of this innovative tool in broader urban research from a social science perspective. Therefore, the methodological standpoint adopted could be called ‘empirical exploration’ of a new research methodology itself.

The research technique selected for this dissertation consists of a series of mobile phone location tests that surveyed the movements around the city of Leicester of a group of 9 people, plus further accuracy tests of mobile phone operators. This approach was finally adopted after having first tried to obtain mobile phone location data directly from the operators or their third party service providers (TPSP), with unsuccessful results due to privacy concerns and commercial reasons. The location data collected through these tests, together with GPS data for actual positions, mobile phone base station information, and general urban cartography, have been all mapped into a GIS package using *ArcGIS*, and processed using *Tracking Analyst*, and *Spatial Analyst* extensions.

4.1. Research Design

4.1.1 Dataset originally pursued

An original proposal of collaboration was sent to mobile phone operators and third party service providers (TPSP) in the UK⁵ but did not receive any support from them. The dataset pursued would have contained location information for either; a group of mobile phones whose owners would all live within the boundaries of one Census Output Area (OA) (people-based, with same place of origin), or any mobile phones that would move to, from, or through a particular area, such as a city centre (place-based). Raper (2000) has also proposed these two approaches to the study of individual movements, as either ‘monitoring objects’ (people-based), or ‘monitoring space’ (place-based).

Several proposals were made to make sure the anonymity of records was kept (such as replacing telephone numbers with sequential numbers, or introducing a ‘rounding’ in the geographical accuracy of the phone location around the person’s place of residence to the nearest 100 m. in urban areas). Nevertheless, this request was not successful basically due to the restriction present in the contracts both between the user and the mobile phone operator, and between the latter and the third party service provider (TPSP), preventing the disclosure of any location information without the explicit consent of the user⁶. Some type of individual data aggregation, would have allowed to get around these restrictions, but this alternative could not be fully discussed with the right people in these companies. Thomas (2003) tried to access mobile phone call information in the UK in a different research and was also unsuccessful⁷.

Due to the restrictions to access mobile phone location datasets, and the time and budget constraints of this MSc dissertation, it was decided to abandon the direct approach to these companies and pursue a different data collection path.

⁵ A total of 5 mobile phone operators and 12 TPSPs were approached. See Appendix for a full list and details of these companies.

TPSP: Third Party Service Provider. A company different from the mobile phone operators that provides value-added LBS services to the final user, in this case the location data of mobile phones subscribed to the service.

⁶ Restrictions on the release of location information have been found in clauses in a contract for an O2 pre-pay phone, and in the terms and conditions regulating the on-line services when subscribing to the following TSPS; Childlocate, FollowUs and WayHey.

⁷ Thomas, B (2004) Personal Communication by e-mail 26/05/2004

4.1.2 Data collection strategy finally proposed

Even when a dataset that would be representative of a group of population could not be obtained from these companies, nothing prevented the research to build a smaller but similar dataset 'buying it' through subscription to some of these TPSPs and locating a small group of volunteers.

A series of three different tests of mobile phone location were carried out in order to generate a minimum dataset that would enable the desired analysis to be performed. The mechanics of each of these tests and their objectives will be individually explained in section 4.2 below, and the overall results in the next chapter. All of these tests basically consisted in locating several mobile phones through some of the TPSPs that offered a commercial option to track mobile phones with the consent of each user (see the Appendix 1 for a full list of TPSP available in the UK in June 2004 and their service details). The differences between the tests reside in the aim of each test, their geographical coverage, and the stages in which they were developed, providing different settings for the subsequent analysis of the data.

The first test aimed to measure the mobility patterns of a group of students in the city centre of Leicester. Since this test found that the location accuracy provided by the operators was much more poor than advertised by the TPSPs, it was clear that a full test of the actual accuracy in different areas of the city was necessary in order to evaluate the true potential of this technology. This second test consisted in locating mobile phones from different operators, covering several areas of the city of Leicester, comparing the locations provided with their true location via a GPS unit. A third test was carried out measuring inter-urban movements, by tracking a single mobile phone during several car trips around the UK, offering a much more useful scale of analysis to be used with this methodology. An overview of the three tests general characteristics is summarized in Table 4.1.

Table 4.1. Summary of Location Tests performed

Test Nr.	Objective	Nr. of mobile phones located	Nr. of Time Location Stamps (TLS)	TPSP
1	Test <u>intra-urban mobility</u> patterns of 9 people	9	152	<i>ChildLocate</i>
2	Test <u>location accuracy</u> of mobile phone operators	3	83	<i>FollowUs</i>
3	Test advantages of mobile phone location for <u>inter-urban mobility</u> pattern analysis	1	74	<i>FollowUs</i>

4.1.3. Pilot Test

An initial pilot test was carried out using three TPSPs (*Childlocate*, *FollowUs*, and *WayHey*) and two mobile phones from different operators (*O2* and *Vodafone*), in order to explore and compare their subscription processes, the pricing systems, the systems to deliver the geographical location information, and the location accuracy differences by TPSPs and by operator. These 3 TPSPs were pre-selected out of an initial list of 12 (see Appendix) due to their lower cost and a price structure that was more beneficial for the test, together with the ease of use in subscribing mobile phone ‘locatees’⁸, and in using their internet interfaces to display, store and process the location information requests.

The TPSPs registration process is especially relevant to this dissertation. The phones that were to be tracked automatically received an SMS message indicating that the author of this dissertation was requesting permission to track their mobile phones, giving instructions to send back a confirmation message if they agreed. The three TPSPs present a similar registration procedure, while some other ones include further security measures, such as the need to fax proof of employment (in the case of employers wanting to track employees⁹), or the actual mobile phone invoice with a written signature.

The second part of the pilot test concerned with testing the mobile phone location process, and it consisted in locating 4 times each of the 2 pilot test phones in each of the 3 TPSPs. From this preliminary test it was concluded that there were no location

⁸ Locatee: The person whose mobile phone someone else is trying to locate

⁹ *Verilocation*

differences between TPSPs (i.e. the location estimate always comes from the operator), although there were significant location variations between operators for the same user position (i.e. the operators use different positioning systems based on different networks). Furthermore, *Childlocate* proved to be the least expensive solution for a volume test¹⁰, and was therefore selected as the TPSP for test 1, where volume of locations was high. Nevertheless, *FollowUs* was preferred for test 2 and 3 due to the enhanced service options that will be mentioned below.

4.2. Mobile Phone Tests Implementation

4.2.1. Test 1 – Intra-urban mobility of a student group

The test 1 objective was to measure the intra-urban mobility pattern of a small sample of students living in the same area of Leicester, through a series of mobile phone ‘time-location stamps’ (TLS)¹¹ taken at different times during several days.

The rationale behind only selecting people sharing a close place of residence was to try to demonstrate the value of aggregating the individual movements into overall patterns by OA of residence. Furthermore, the reason for constraining the geographical area to intra-urban movements was to be able to analyse the data in large cartographic scale at an equivalent to postcode unit level, which could not have been shown if people moved frequently outside the city limits.

The selected geographical area of residence was located around a large student hall of residence (700 rooms), so that the anonymity of the participants would be guaranteed. Due to the budget constraints of this research, the original sample size was targeted at 10 to 15 students, which would be tracked during 2 days at various time intervals (an average of 6-8 locations per day). The way to approach the potential participants was an invitation letter sent by e-mail (see Appendix 2) through different networks of friends, since the sensitivity of information requested (personal location) demanded a minimum

¹⁰ The original estimated number of location requests was around 200 locations, and *Childlocate* location requests cost £0.2 /location x200= £40 + £6 monthly fee = £46

¹¹ The concept of ‘time-location stamps’ (TLS) will be used in this dissertation to refer to a record that stores both the geographical location of a mobile phone (in a pair of coordinates), together with the date and time at which such location was measured.

level of trust about the researcher that could not be expected from anonymous random participants. Therefore, the results of the test do not pretend to be representative of the student population in the area, but just the first illustration of how this technology can be used for future similar but broader and truly representative studies.

Finally, a group of 9 students that fell within the established logistical requirements (see Appendix 2) agreed to participate in the test, representing three mobile phone operators (O2, Vodafone, and Orange). Six of these students lived in the same hall of residence while the other four shared a house located 1 km. away from the mentioned residence. The former were international postgraduate students, while the latter were British nationals, undergraduate or graduate students who had lived for at least 3 years in Leicester. The fact of having two such different groups was judged to later provide interesting conclusions when comparing their mobility patterns.

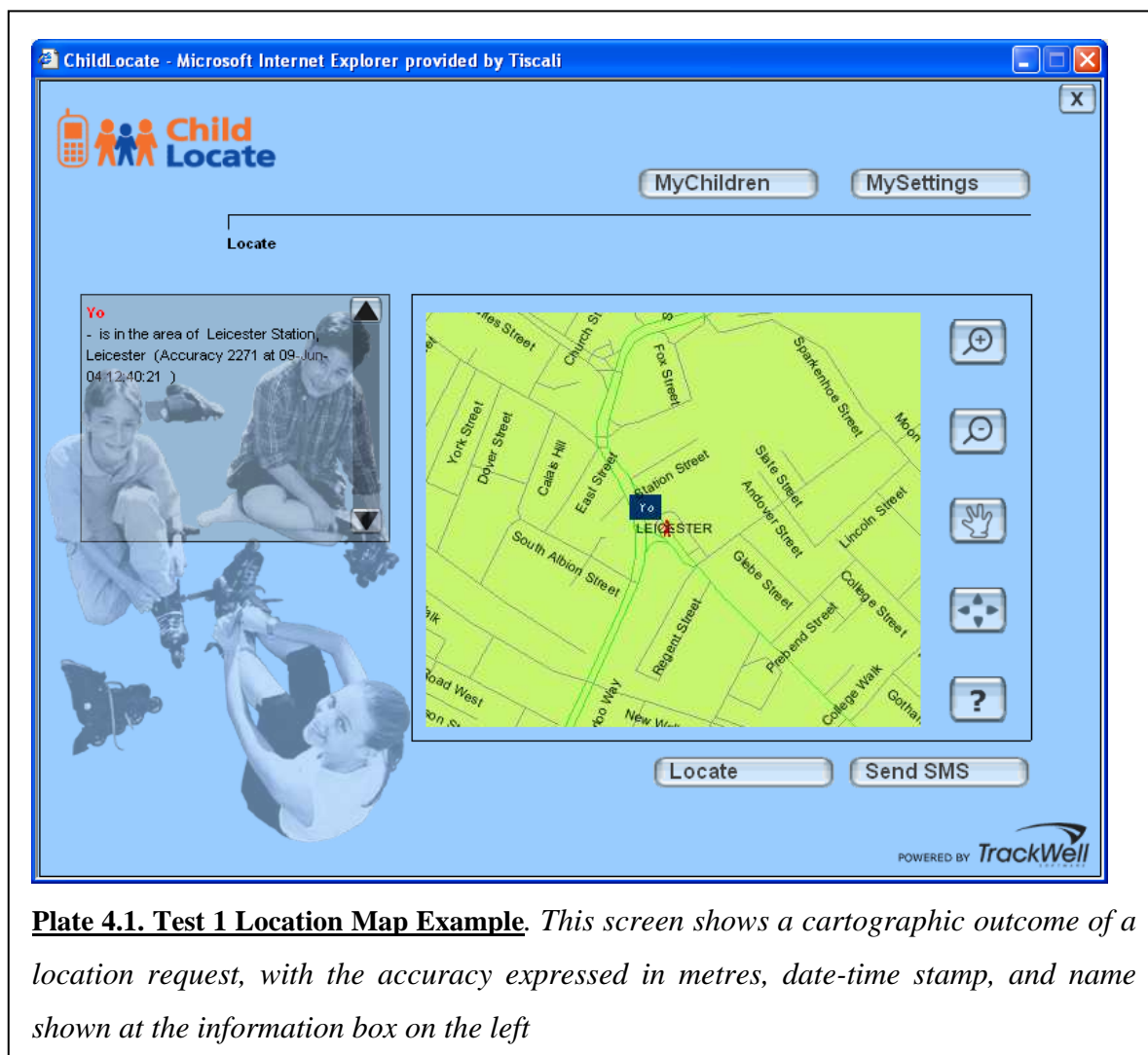


Plate 4.1. Test 1 Location Map Example. This screen shows a cartographic outcome of a location request, with the accuracy expressed in metres, date-time stamp, and name shown at the information box on the left

One account was opened with *Childlocate*, where the 9 students' mobile phones were initially registered, after all participants had sent their SMS back to confirm. The actual location tests were carried out during 3 consecutive weekdays in June 2004, at various temporal intervals each day and always within non-sleeping hours (typically 9:00 to 21:00h), in order to compare the outcome of several temporal resolutions in the data. The total number of location requests was 159 at an average temporal interval of 2.5 hours. The breakdown by day is shown in Table 4.2.

Table 4.2: Test 1 summary of location requests per day

Date	Nr. of Location Requests	Avg. Daily Requests/ 'locatee'	Temporal Resolution (hrs)
Wednesday	58	5.8	2.1
Thursday	59	5.9	2.0
Friday	42	4.2	2.9
OVERALL	159	5.3	2.3

The location requests were manually placed at the TPSP web page (*Childlocate*), one participant at a time. The TPSP then provided a map on the screen with the location of the mobile phone giving an estimate of the location accuracy (in metres) of such position (see Plate 4.1), that were stored as an image file for later processing. Only 7 requests out of the 159 were not successful (availability rate of 95.7%). The breakdown of the resulting 152 TLSs (Time Location Stamps) obtained by operator is shown in Table 4.3.

Table 4.3: Test 1 Overall Settings

Operator	Nr. of 'Locatees'	Nr. of Location Request Attempts	Nr. of Time Location Stamps (TLS)	Success Rate (%)	Nr. Of Location 'Milestones'
O2	1	15	13	86.7%	5
Orange	1	20	20	100.0%	6
Vodafone	7	124	119	96.0%	13
TOTAL	9	159	152	95.6%	24

The common locations of TLS were manually digitized as points using *ArcGIS*, finding each location on the map provided by *Childlocate* (see Figure 4.1) in a street cartography of Leicester city centre (created from *OS LandLine* available through

EDINA-Digimap). A *Geogedatabase*¹² was finally created with all TLS location coordinates in addition to the following attribute fields:

- ❑ Participant ID
- ❑ Mobile Phone Operator
- ❑ Date and Time of the Location Request
- ❑ Date and Time of Reported Location
- ❑ Reported Accuracy of Location

Due to a requirement of the *ArcGIS* extension *Tracking Analyst*, the date-time fields had to be formatted in a way that both the date and the time would form part of the same variable, for the extension to be able to perform space-time analyses. The time precision was kept at seconds level, to enable subsequent accurate temporal comparisons.

4.2.2. Test 2 – Assessing Mobile Phone Location Accuracy

Test 2 objective was to find out the actual geographical accuracy of the mobile phone locations provided by the operators, and analyse the differences between them, and throughout the different areas of the city centre of Leicester. The test was designed to be able to check the reality of mobile location methods and their accuracy, as reviewed in section 3.4, contrasting it with the results of test 1.

The test consisted in carrying together 3 mobile phones from different operators (*O2*, *Vodafone* and *T-mobile*)¹³ plus a GPS (*Garmin GPS 12XL*) driving and walking around the city centre of Leicester, while location requests for the mobile phones were placed on the TPSP website through one of the phones (a Pocket PC ‘smartphone’ with GPRS internet access, see Plate 4.2). The chosen TPSP for this test was *FollowUs*, because it offered a facility to access historical location queries (*Childlocate* only offers a location in ‘real-time’), so that all locations could be accessed later in ‘one go’. Moreover, the information about the locations could be accessed as a pair of British National Grid (BNG) coordinates at 1m accuracy (although through an indirect way, see Plate 4.3), substantially facilitating the transfer of the data to the GIS.

¹² The Database Management System of *ArcGIS*, whose format is a Microsoft Access proprietary format. MS Access was used to perform some of the queries and data manipulation.

¹³ Due to a problem with the registration of the *Orange* mobile phone on the day of the test, location data could not be gathered for this operator.



Plate 4.2: *GPS and Mobile phones used for Test 2(Pocket PC smartphone at the right)*

The temporal resolution of the mobile phone location requests was considered irrelevant, because the importance of the test was to cover a dense number of different locations within the study area despite time intervals. The test was carried out in two separate days and 87 location requests were placed from different points scattered around the study area, with different availability responses by operator.

A total of 83 TLS were then recovered from *FollowUs* history request webpage (Plate 4.3) including the BNG coordinates of the locations, and incorporated in a database. The GPS data was downloaded and imported into a different table of the same database. In order to allocate a GPS location to each TLS (the true position vs. the mobile phone location) a query was designed to join both database tables and sort GPS and TLS records by their closest time stamp. This was an interesting example of the value of a temporal query over a spatial one, since each TLS had to be assigned with its closest GPS point in time not necessarily in space. After this, an algorithm was programmed to calculate the straight line distance between each TLS and the true GPS location, in order to compute the real accuracy of each TLS.

Plate 4.3: *FollowUs History Request Screen*
(names and telephone numbers anonymised in green)

history request

Start date: 13 / 6 / 2004
End Date: 13 / 7 / 2004

• search dates

View	Place Name	Area	Postcode	Time Date	Name	Number
• view	Aylestone	Leicester Leicestershire	LE2	Mon Jul 12 18:55:49 BST 2004	[Anonymised]	4479314...63
• view	Aylestone	Leicester Leicestershire	LE2	Mon Jul 12 18:52:11 BST 2004	[Anonymised]	4479314...63
-1-				Mon Jul 12 18:46:33 BST 2004	[Anonymised]	4479314...63
• view	Aylestone	Leicester Leicestershire	LE2	Mon Jul 12 18:43:39 BST 2004	[Anonymised]	4479314...63
• view	Rowlatts Hill	Leicester Leicestershire	LE5	Mon Jul 12 18:36:55 BST 2004	[Anonymised]	4479314...63
• view	Belorave	Leicester	LE1	Mon Jul 12 18:30:43 BST	[Anonymised]	4479314...63

account credits: 26.75
buy top-up locations here
click on the name below that you want to locate
My group
organise your names into groups
My group
• create group • modify group • delete group

Orange - 100% OK
Vodafone - 100% OK
O2 - 100% OK
T-Mobile - 100% OK

• purchase credit policy • terms and conditions • user agreement • privacy policy

© FollowUs 2002-2004

javascript:MM_openBrWindow('smallView.jsp?x=458210&y=301973&z=1629&num=447931456363','closeup','scrollbars=yes,width=500')

So far none of the steps described for Test 2 required the use of a GIS, but only a database was sufficient to achieve the main objective of the test. This shows the fact that personal location data, although intrinsically spatial, can be first exploited in an database management system (DBMS) with a high degree of success (Nedas and Egenhofer 2003). Nevertheless, this presents serious challenges to traditional DBMS regarding how to model complex space-time relationships, as it will be mentioned later in section 5.5.

However, both the GPS and TLS datasets were finally incorporated in *ArcGIS* in order to show not only the geographical accuracy of the mobile phone measurements, but also the differences in the route patterns. This was achieved through the extension *Tracking Analyst*, that links all data points from the same entity (in this case each mobile phone owner and the GPS) ordered by date-time stamp.

Finally, an additional data layer was built with the location of mobile phone base stations in the study area, in order to test whether the TLS locations coincided with base station locations. This layer was semi-automatically digitized from the raster maps found at *SiteFinder* (<http://www.sitefinder.radio.gov.uk/> June 2004 release used) The geodatabase built was enriched with attribute data about the characteristics of each base station, such as total height or transmitter power, coming from both *SiteFinder*. This information would allow to test whether the accuracy estimate given by TPSPs was related to the base station signal reach.

4.2.3. Test 3 – Exploring Inter-urban mobility

The objective of Test 3 was to assess the advantages of mobile phone location in measuring inter-urban mobility patterns as opposed to the intra-urban ones in Test 1. Test 3 was envisaged as an additional experiment to find the best scale of application for mobile phone location technology, in order to point out directions for further research.

The test consisted in measuring both mobility patterns through the location of a mobile phone (a single operator in this case; O2) while moving between cities in the UK at distances between 100 Km and 300 Km. In order to perform this test, the TPSP chosen was again *FollowUS* due to their ability to program automatic location requests, that for this test were set at every hour from 6:00 am to 21:00 (the maximum temporal resolution allowed by this TPSP). Even though, the location requests to this TPSPs are more expensive than *ChildLocate*¹⁴ and therefore the test could only be carried out for a few trips and periods of time, as shown in Table 4.4.

Table 4.4: Test 3 summary of measured trips

Trip Nr.	Date	Origin	Intermediate Place	Destination	Nr. of Time Location Stamps (TLS)
1	12-Jul-04	Wakefield	Leicester	Wakefield	12
2	19-Jul-04	Wakefield	n/a	London	11
3	20-Jul-04	London	n/a	London	11
4	12-Aug-04	Wakefield	Leicester	Wakefield	14
5	13-Aug-04	Wakefield	Manchester	Wakefield	11
6	14-Aug-04	Wakefield	Whitby	Wakefield	15
TOTAL					74

¹⁴ Cost per location request: FollowUs = £0.33 vs. ChildLocate= £0.20

The TLS data was retrieved in a different way for this test, since the automatic location requests to *FollowUs* send back an e-mail with the mobile phone's position (see a sample of the e-mail in Appendix 4). The relevant information (mobile phone number, location coordinates, date-time stamp, postcode, etc) was retrieved from the e-mail and imported in *ArcGIS* geocoding the information and computing tracks through Tracking Analyst.

5) PRESENTATION AND ANALYSIS OF RESULTS

This chapter will present and analyse the results of the tests and its data analysis in GIS. The final discussion and recommendations for this methodology will be presented in chapter 6.

5.1) Intra-urban mobility (Test 1)

As it has already been mentioned, the results of test 1, aimed at measuring intra-urban mobility, were very deceptive in terms of the mobile phone location accuracy provided. Nevertheless, the test not only provided the motivation to perform the other two tests, but also offered interesting insights into the future applications of this technology once the desired accuracy is available.

Milestones and Cells

In the first place the test revealed that the mobile phone location estimates provided by the TPSP (who obtains them straight from operators) always coincide with a common point that will be called here ‘*milestones*’ for simplicity. The 152 TLS obtained in the test were all located at 24 ‘*milestones*’, and the location accuracy estimate was always the same at each ‘*milestone*’ (see Map 5.1). The main reason for this seems to be that the mobile phone location method used by all the operators is the simplest of those described in chapter 3 (section 3.4), that is *Cell-ID*. In section 5.2, further analysis on the location of each operator base stations compared to the *milestones* locations will be presented.

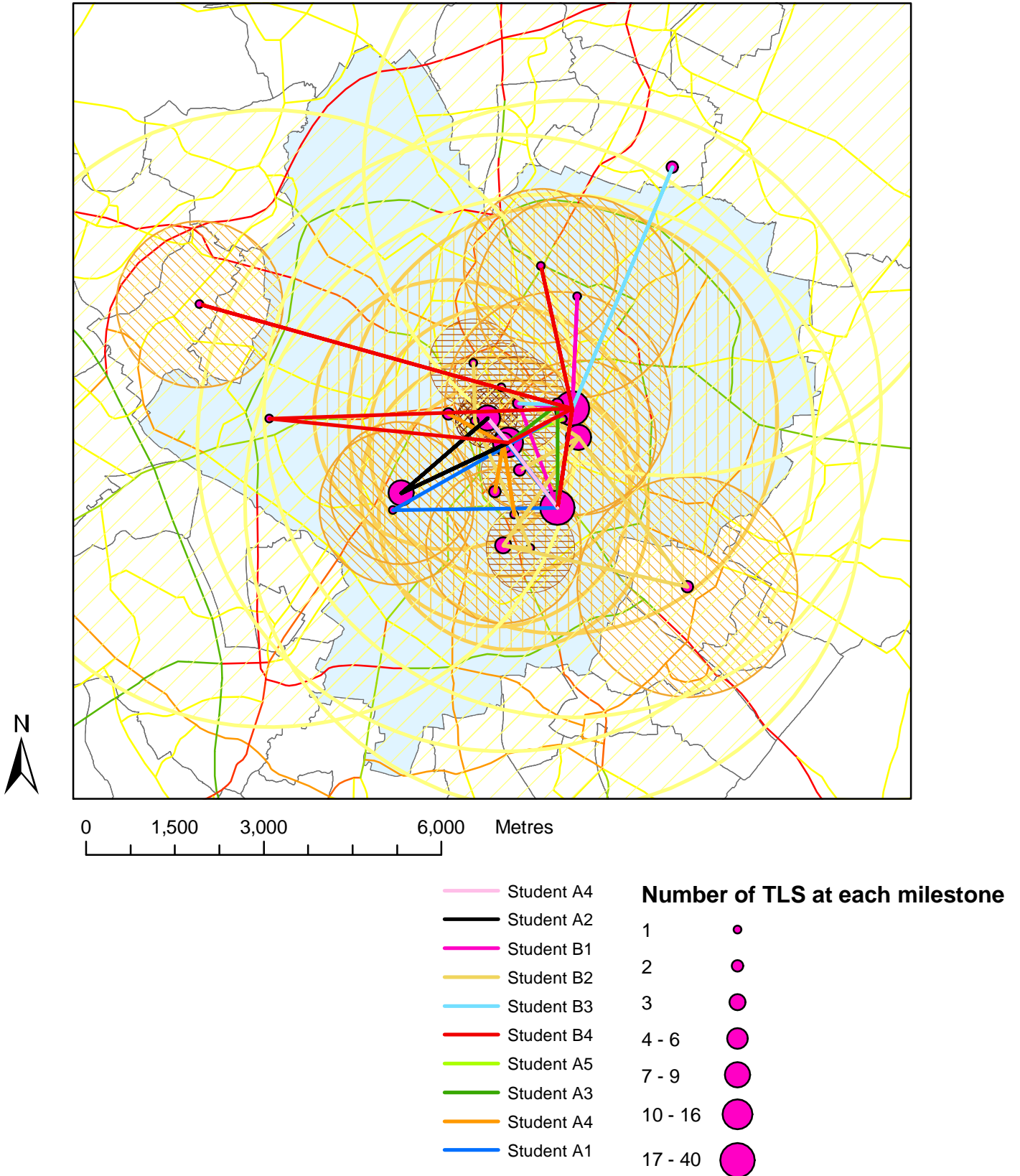
Location Accuracy

According to Faggion & Trocheris (2004) Cell-ID location method provides a location accuracy between 500 m and 10 km (from urban to rural areas). Although the reported estimated accuracy for Test 1 TLS were all between 326 m and 5.2 km, and hence within the theoretical range (see Table 5.1), 82% of the locations are above 1,300 m accuracy,

Table 5.1:
Test 1 Min and Max Location Accuracy per operator

Operator	Location Accuracy (m)	
	Min	Max
O2	2271	3615
Orange	326	1855
Vodafone	500	5200
ALL	326	5200

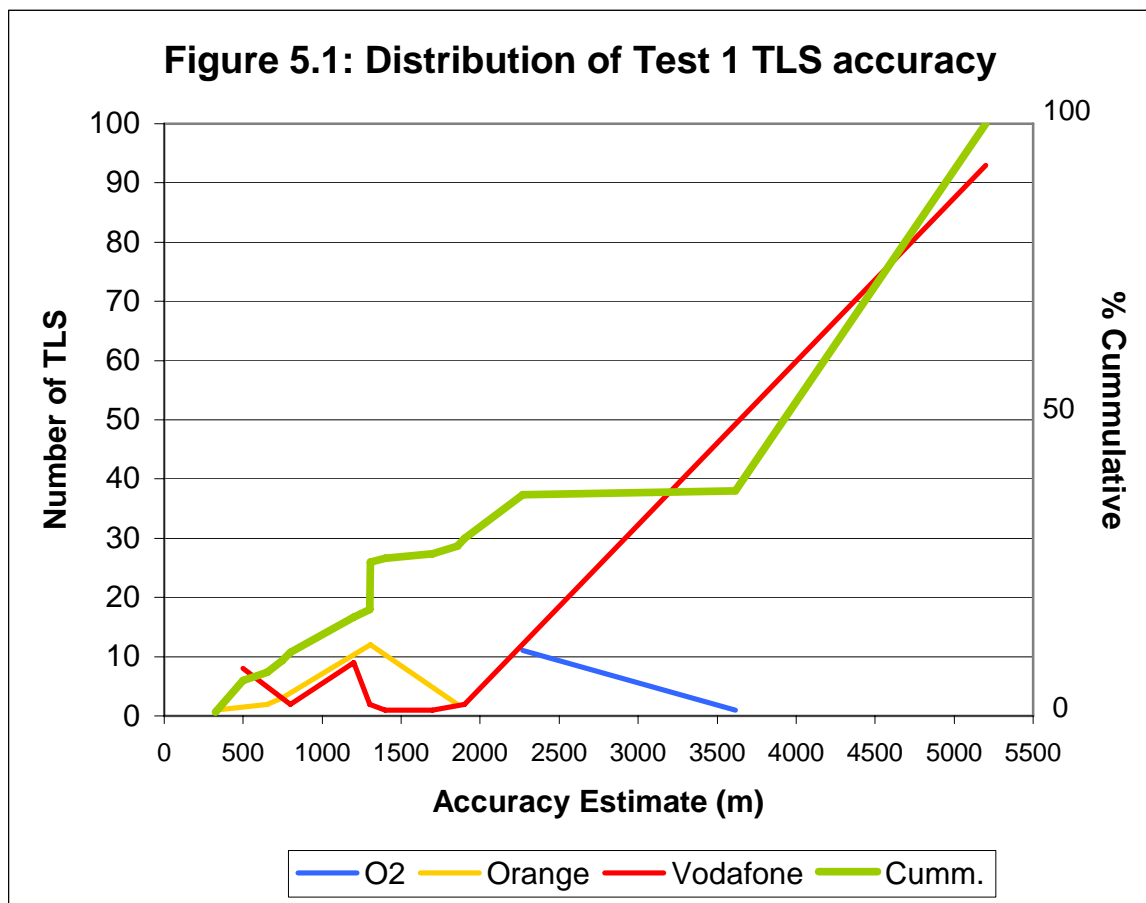
Map 5.1: Test 1- Milestones and Estimated Accuracy



The map shows the location of the 'milestones' reported by the TLS with varying intensities according to their number of 'visits' (pink), and the size of each cell as a circle or radius= reported accuracy. Additionally the traces of the 9 students are also shown

and 62% still above 3,615 m (see Figure 5.1). In other words, interpreting the test results with such location accuracy ranges would mean that more than half of the mobile phones located could be anywhere within a 3.6 km radius around the city centre, that is within an area of 11 sq km. (see Map 5.1; accuracy radius).

These figures are very disappointing indeed for a medium size city centre, and substantially contradict the accuracy estimates advertised by the TPSP¹⁵, that in a similar UK metropolitan area claim an accuracy of 150-400 m. These estimates, together with an study of mobile phone location published by Hato & Asakura (2001), that claimed accuracies of 30-200m, where the factors that made this research choose a intra-urban scale for the first test.



A difference per operator though can be noticed (see Table 5.1), since *Orange* TLS are within 326-1855 m range and 90% of them below 1,304 m, as a consequence of a newer

¹⁵ ChildLocate advertises these accuracy estimates figures at:
<http://www.childlocate.co.uk/faq.html>
<http://www.christmas-shopping-uk.com/locateyourchildren.htm>

network with smaller cells and many *microcells* in the city centre (see Map 5.2). This is a small ‘sign of hope’ for the methodology proposed in this research, as network enhancements roll-out across all operators.

This disappointment with the results of Test 1 brought the research to focus on a deeper study of the variables affecting location accuracy, taking as a study area the city centre of Leicester that will be analysed in Test 2.

Visualising Intra-urban mobility

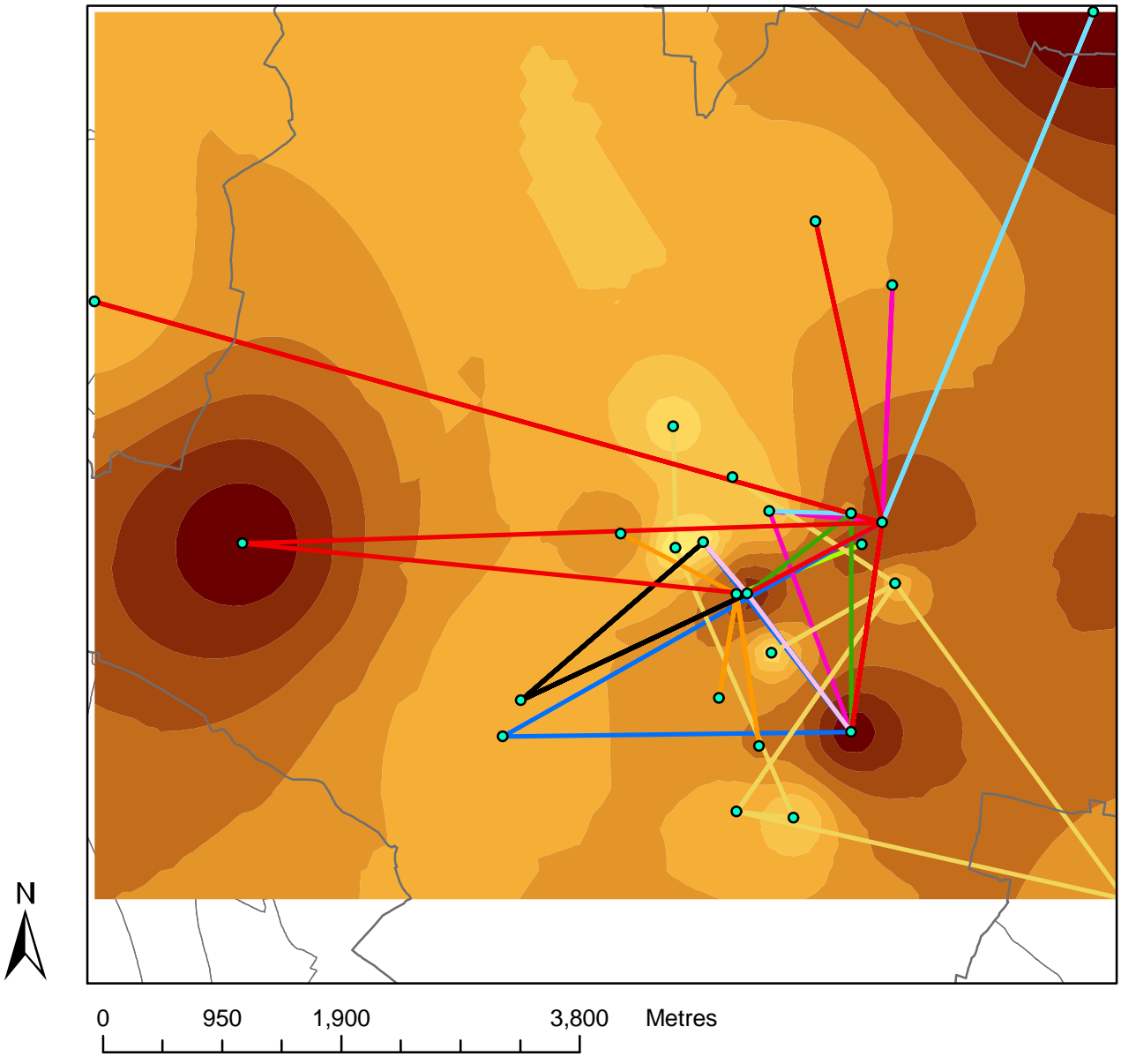
Although the test on intra-urban mobility did not provide the expected minimum location accuracy levels, the results are still interesting in drafting out the possible applications of this technology in the immediate future (i.e. before accuracies in the 100m range are common place).

If we interpret the results of TLS at ‘*milestones*’, as the locations of participants within a limited number of cells (24 cells in this case), and their movements between them, interesting conclusions can be derived.

There is a very different mobility pattern between the two group of students measured. Group A, is comprised of 6 international postgraduate students who lived in a Hall of residence close by the main university campus, and had only been the academic year in Leicester. During the test days they did not move much from the area comprised around the University Campus, neighbouring Victoria Park or the city centre of Leicester. On the contrary Group B is comprised by 4 British students who had been undergraduates at Leicester, might have access to a car or command well bus routes, and definitely know well the city. As show in Map 5.1 their mobility pattern show a much broader use of the city that Group A, frequently accessing the suburbs.

It is obvious that these rough conclusions could have been verified by surveying the 10 participants, asking them for additional data to start analysing their mobility patterns with greater precision. However, the aim of the research is to propose an ‘automatic’ and passive monitoring system of mobility were participants do not feel observed in their movements, and that can be applied to a mass group of population without necessarily having to complement it with additional survey information.

Map 5.2: Test 1- Surface map of Accuracy Ranges (IDW interpolation)



The map shows an interpolated surface with ranges of location accuracy intensity

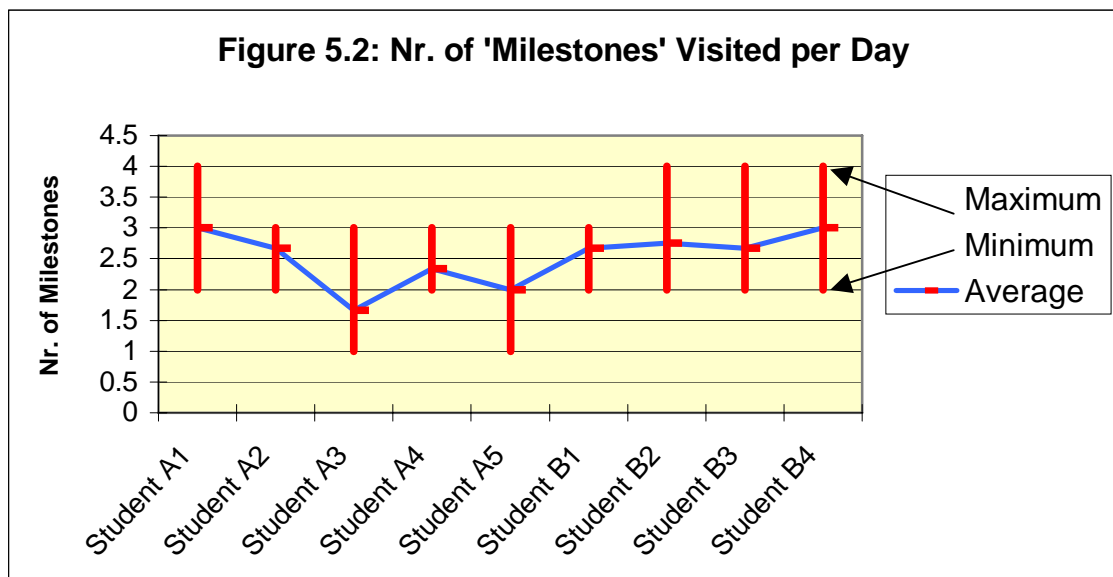
Test 1 Participants Location Accuracy Surface (IDW)

- Student A4
- Student A2
- Student B1
- Student B2
- Student B3
- Student B4
- Student A5
- Student A3
- Student A4
- Student A1
- Milestones

Accuracy ranges (m)

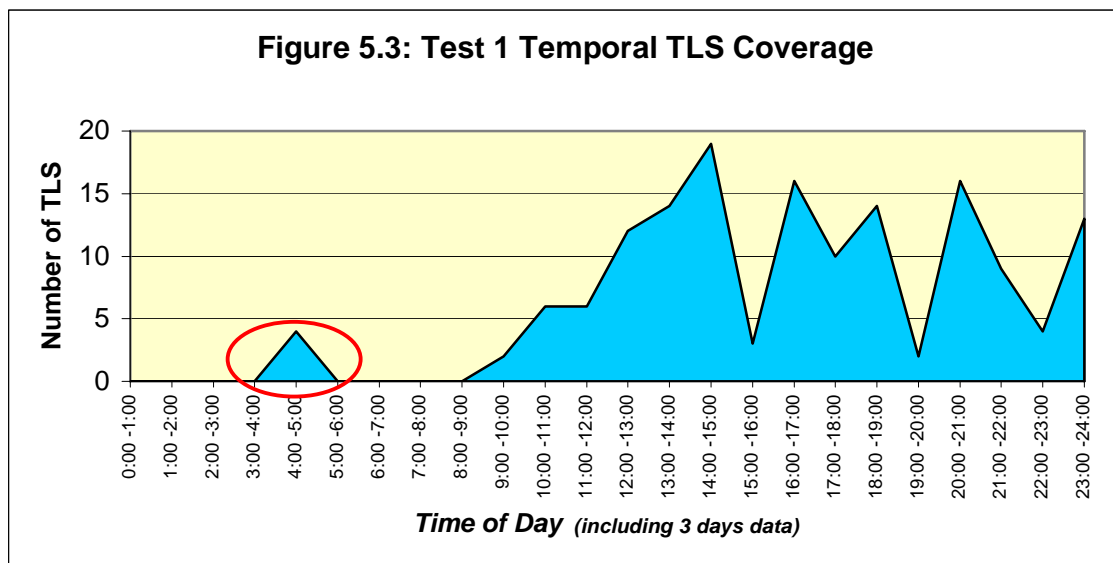
	326 - 499
	499- 713
	713 - 976
	976 - 1300
	1300 - 1699
	1699 - 2190
	2190 - 2794
	2794 - 3539
	3539- 4455
	4455 - 5200

One approach to mine the dataset and find patterns of mobility is to look at the number of ‘milestones’ or cells visited by each participant in a single day. As shown on Figure 5.2 there are substantial differences in the amount of mobility each student group has. The graph shows the minimum and maximum number of different *milestones* (or cells) visited per day in the 3 days the test was measured, and the average per person in the test. It can be noticed that students in Group B present a higher mobility just by looking that they visit at least 2 *milestones* a day and some days up to 4 different ones, while Group A usually move only between 1 and 3 *milestones*. This is another measurement of spatial extensibility (Miller 2004b) measured in number of ‘mobile phone cells’ geographical units.



Temporal Analysis

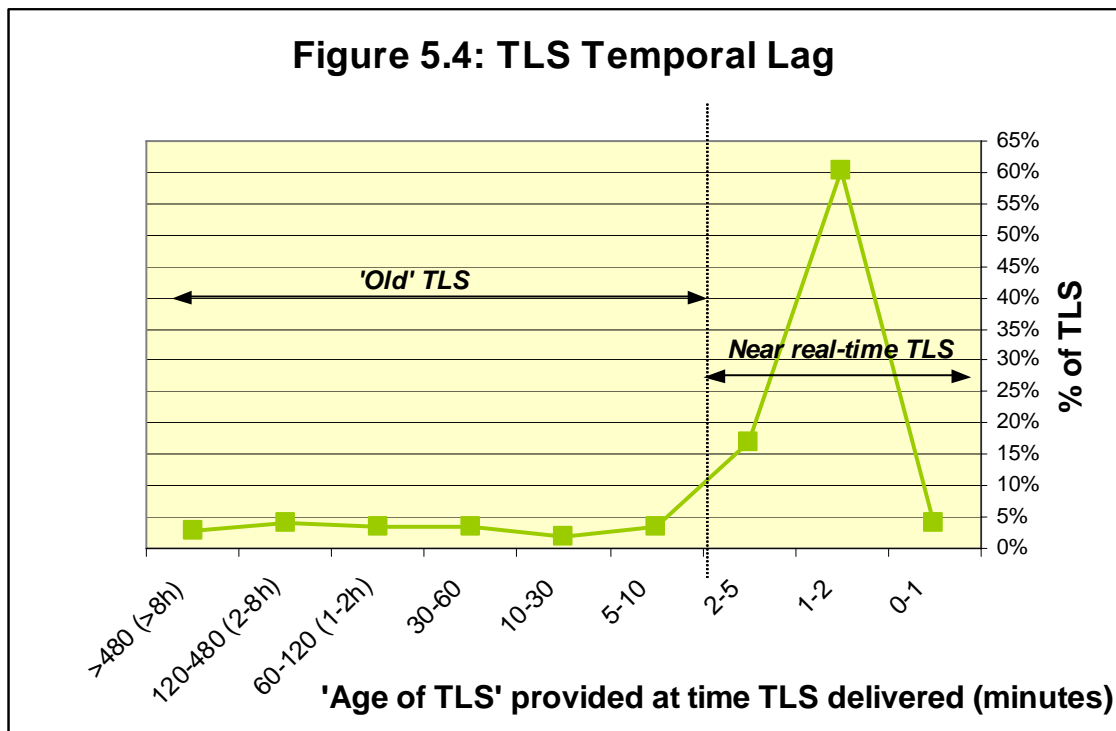
An additional standpoint to analyse this data is its temporal dimension. Looking at the temporal patterns of movements during the three weekdays some conclusions can be drawn from the test. As shown in Figure 5.3 the temporal coverage throughout the three days is not consistent, due to the temporal resolution of the test being an average of 2.5 hours, and the manual process of sending the location requests through ChildLocate website, that left several time slots not evenly covered (e.g. 15:00-16:00 or 19:00-20:00). This fact led to the decision of using automatic location in the next tests.



Furthermore, a temporal outlier was found in the data, with 4 TLS occurring between 4:00 and 5:00 am (see red ellipse in Figure 5.3), when actually the location requests were sent during the day. The time (and therefore the position) provided by the operator in these cases could be the last transaction of the phone that the network might have recorded. This problem introduces another factor to consider in the usage of these datasets; *TLS temporal lag*, ie. the ‘age of the TLS’ delivered with a location request.

Further analysis of ‘TLS temporal lag’ is possible, since the dataset collected two time stamps, the time at which the location request was processed by the TPSP and the time of the TLS itself, that is, the time at which the provided user location was taken by the operator network. The TPSPs claim there should be no significant temporal lag between the two, since their service is promoted as a ‘real-time’ location of the mobile phone. The reality once again proves quite different. As Figure 5.4 shows, 80% of TLS have a time stamp equal to the time the location request was placed or less than 5 minutes old. The 5 minutes threshold is introduced here to allow for differences in computer clocks across servers or mobile phones, so this time difference is considered as a ‘near real-time’ location. Nevertheless, the ‘age’ of some TLS is large, 10% of them are over one hour ‘old’, and that means that the reported location of the mobile phone is actually where it was more than one hour before (and even over 8 hrs. in the test). This opens another field of research that has not been discussed in the literature; *temporal accuracy* of mobile phone location. For many applications this could have tremendous consequences (e.g. emergency services), although not for the type of mobility analyses

proposed in this research, and therefore not any more analysis of its potential causes has been done.



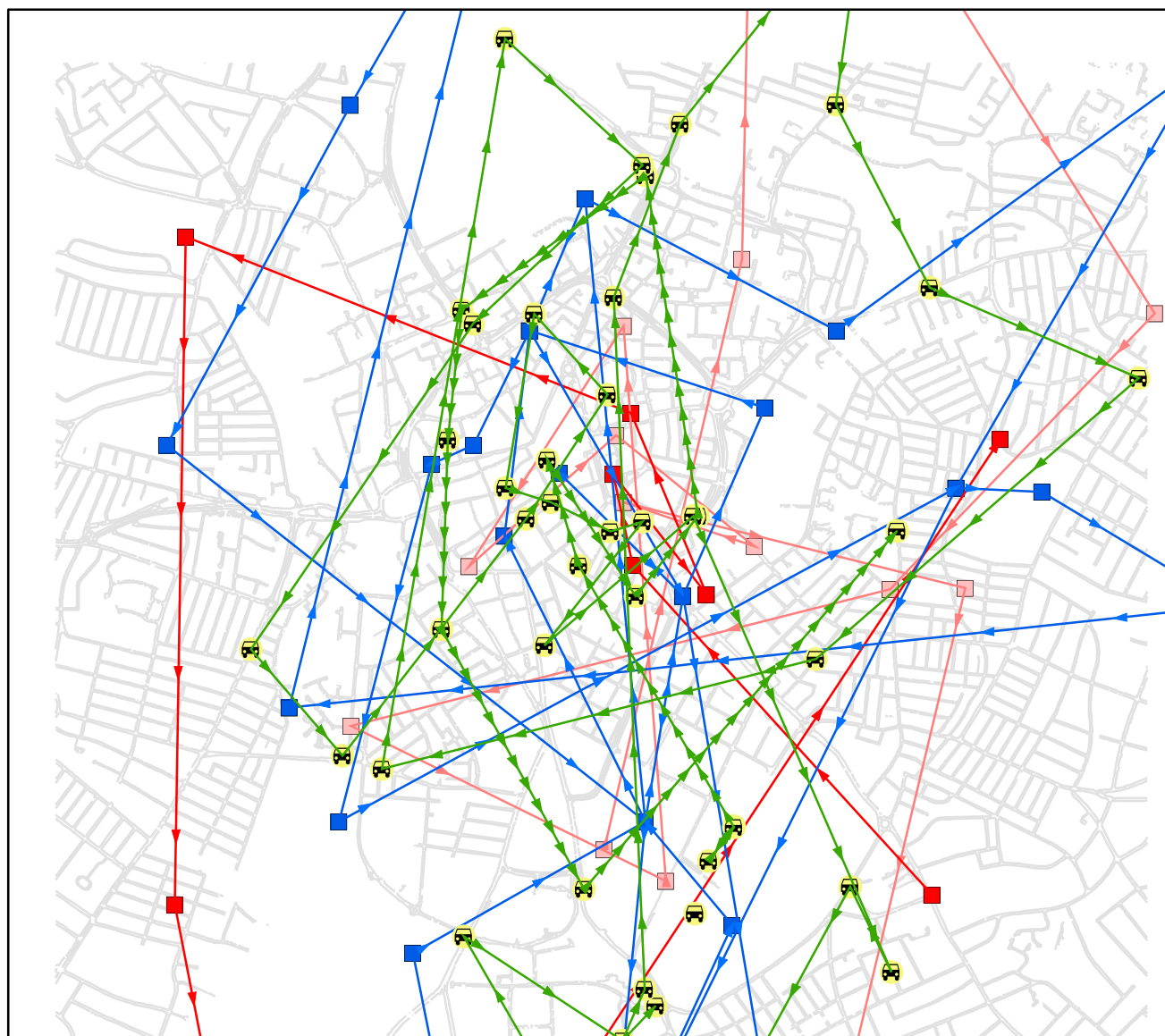
5.2) Location Accuracy (Test 2)

After having found a high location inaccuracy in the dataset collected in Test 1, which provided a base for an initial analysis on location accuracy (see Figure 5.1), Test 2 was carried out specifically to address this task.

True vs. Reported Accuracy

A total of 83 TLS were collected and, as described in the previous chapter, the distance from the GPS location (the true mobile phone location) to the TLS location was calculated (hereinafter the 'True Accuracy'). This distance was then compared with the location accuracy reported by the operator when providing the TLS (hereinafter the 'Reported Accuracy'). The test found that in reality the 'true accuracy' of TLS is much better than reported by the operators (see Map 5.3.) Figure 5.5 shows the average true and reported accuracy per operator and Figure 5.6 provides the descriptive statistics of both datasets. These figures all show a dominant range of true accuracies between 200m and 2000m and averages below 920m, when the reported ones are between 500m and 5000m and averages of 2000-3000m.

Map 5.3 - Test 2- GPS Vs TLS tracks through Leicester



0 395 790 1,580 Metres



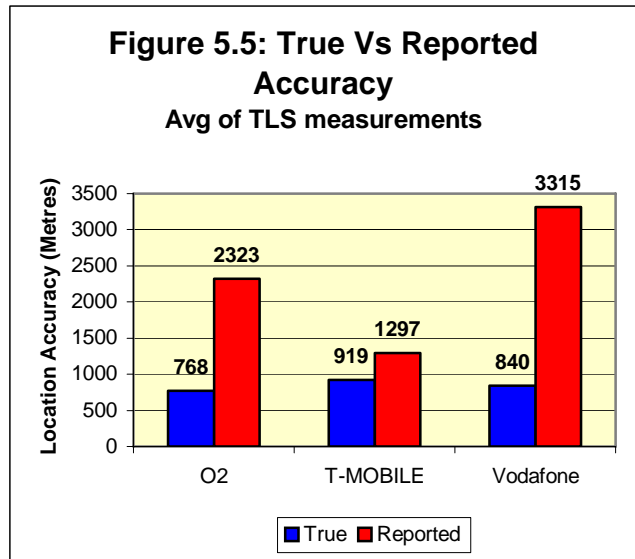
Mobile Phones Routes

- O2
- T-MOBILE
- Vodafone
- O2
- T-MOBILE
- Vodafone

Actual Route (GPS)

- GPS points at TLS time
- Car/ Walk Route

When comparing differences between the three operators measured, the disparities between true and reported accuracies are significant. *T-Mobile* is the operator that is providing accuracies closer to reality, with 41% difference over reality, while *Vodafone* has the largest offset at 295%. Why would operators like *Vodafone* want to provide very

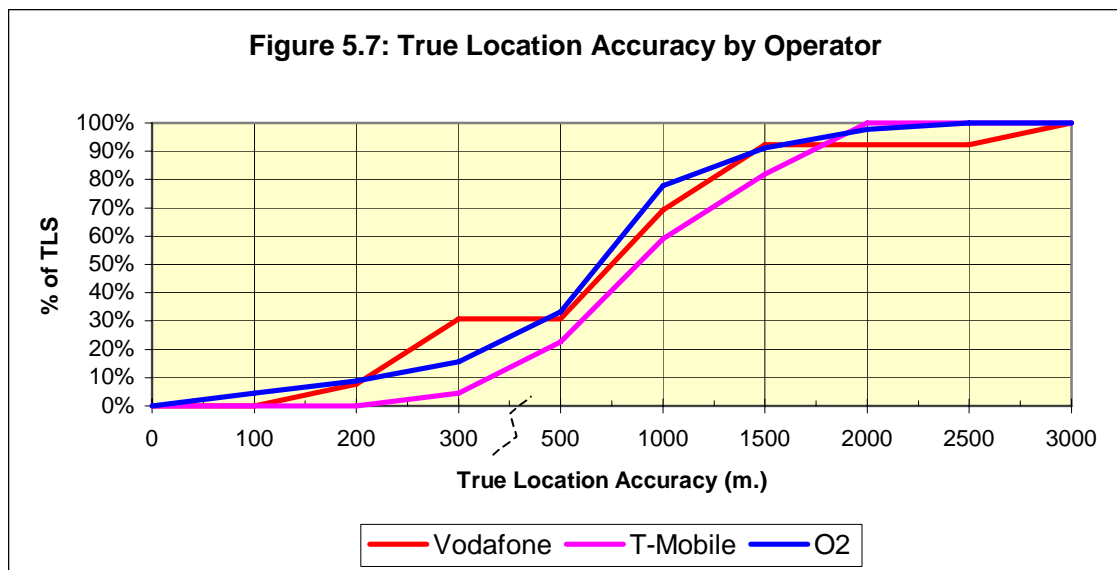


conservative accuracies, when their reality is much better?. Looking at the overall true accuracy *O2*, for which the test collected the higher number of TLS (45), is the most accurate operator in reality, with an average accuracy of 768m and a standard deviation of 480m. Even so, their reported accuracy is nearly as conservative as *Vodafone*'s at 202% over reality in this test.

Figure 5.6: Locational Accuracies Comparison

		Location Accuracy (metres)			
Operator	Nr of TLS	Min	Max	Avg	Std Dev
O2 True	45	63	2005	768	480
O2 Reported		500	3615	2323	755
T-MOBILE True	22	258	1798	919	483
T-MOBILE Reported		941	2105	1297	304
Vodafone True	13	197	2514	840	635
Vodafone Reported		500	5200	3315	2141

In order to analyse in more detail what the true accuracies by operator are Figure 5.7 shows the distribution of the test's TLS by true accuracy distance thresholds, *Vodafone*

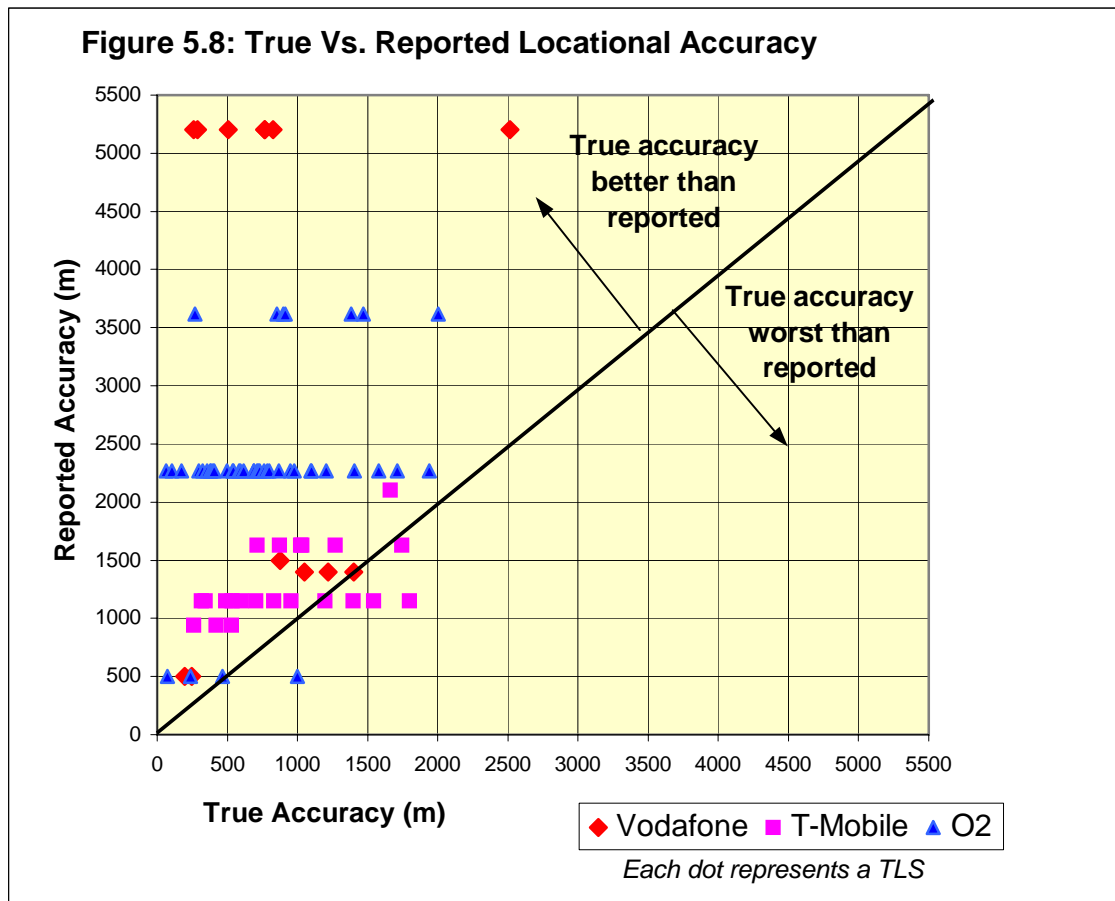


is in this case the most accurate operator in the 300m range, since 30% of their TLS are within this true accuracy, while *T-mobile* is the less accurate in this range at 5% of TLS. In the 1000m range, *O2* is the most accurate at 80% of TLS while *T-mobile* is again the less accurate at 60%. This is interesting because even when *T-mobile* is in reality the least accurate operator (true accuracy average 919m), as it has been said before they are the least conservative when predicting the TLS reported accuracy (41% over reality), and therefore are able to offer the best overall reported accuracy levels (average of 1217m vs. 2323m *O2* and 3315m *Vodafone*). If Test 2 with the GPS had not been done then by looking at the reported accuracies the conclusion would have been that *T-mobile* was the most accurate operator, when the reality is the opposite. How operators market their LBS services is again another factor to consider when using this technology in the future.

Fixed Reported Accuracy

Figure 5.8 compares each individual TLS's true accuracy with the reported one, trying to see any 'correlation' pattern between them. The reality shows that reported accuracies are provided only at certain fixed thresholds while the measured true accuracies are by definition continuous. The test showed a number of 6 reported accuracy distance thresholds when the 3 operators are combined (at 500, 1000, 1500, 2200, 3600, and 5200m). The hypothesis of this research is that these distances are an indication of the size of the cell in which the mobile phone has been located (the radius of the cell measured from the base station), as it will be tried to be proved.

In order to do so, further explanation on how to read Figure 5.8 is required. The figure shows a matrix diagonally divided in two halves, with the diagonal meaning that the reported accuracy is equal to the true accuracy, in other words, that the mobile phone was actually right at the rim of the cell (the radius distance of the cell). The TLS that lie in the top left half of the matrix have a better true accuracy than the reported one, and it gets better the further it departs away from the main diagonal line, as the mobile phone got closer to the base station (values of true accuracy approaching 0). The TLS in the bottom right half of the matrix have a worst true accuracy than reported, in other words, the mobile phones were actually outside the reported accuracy distance, but since these

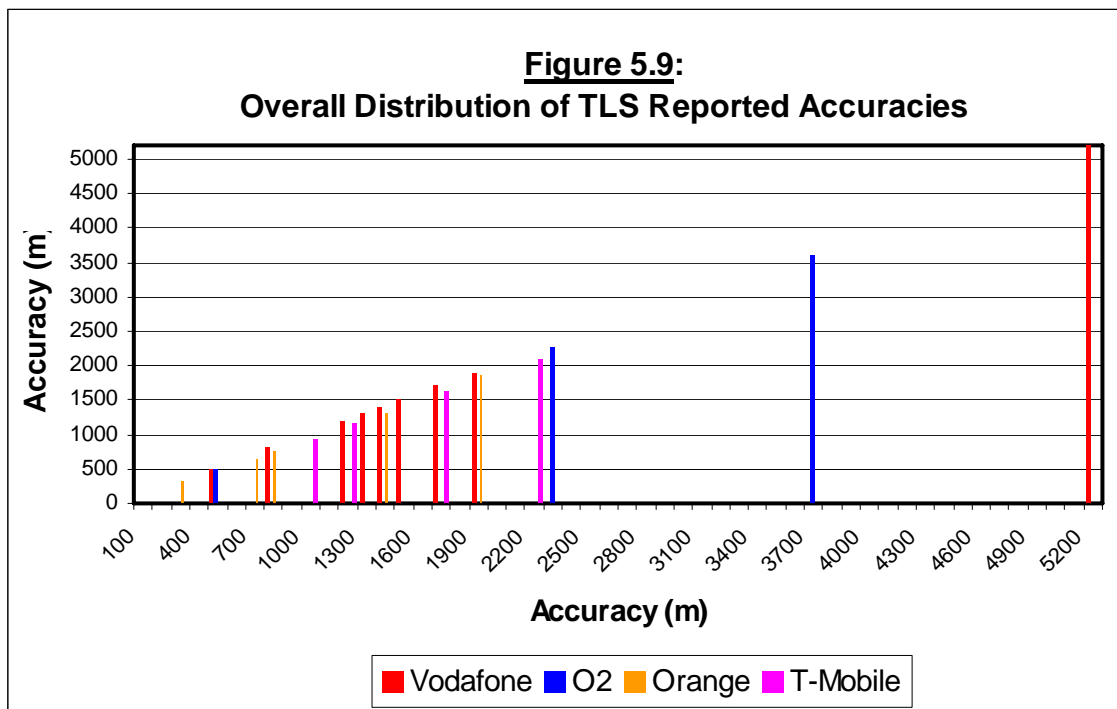


distance are usually very conservative there are much less TLS in this half¹⁶. As it can be then appreciated, although the operators provide reported accuracies at certain fixed thresholds the closer the mobile phone was to the base station (i.e. to the TLS location), the better the true accuracy is. This explains why there are such enormous differences between reported and true accuracies, such as for example some *Vodafone* TLS with a reported accuracy of 5,200m and a true one of 288m (top left). Through these facts it can be concluded that the location methodology used by all operators is Cell-ID, and not even its slight enhancement Cell-ID++. As it was explained in section 3.4, the Cell-ID++ method would have reduced the accuracy estimates to certain perimeters around each base station, based on the estimated distance of the mobile phone (Faggion and Trocheris, 2003), but this is not happening in reality since the accuracy distance thresholds are fixed.

¹⁶ As previously discussed, please notice the *T-Mobile* exception in Figure 5.8 bottom right half.

The impact of historic network development

Furthermore, the fact that all TLS reported accuracies fall within one of the 6 thresholds mentioned, points to a typology of cell sizes related to the base station transmitter power and maybe the type of technology. When considering all the TLS collected in Tests 1 and 2 the range of thresholds increase for the 4 operators, but certain patterns can be appreciated (see Figure 5.9). Most accuracies reported fall between 500m and 2,100m at increases of approximate 100m. *Orange* shows the range of accuracies of shortest distances (all below 1,855m), while *O2* and *Vodafone* provide the largest ones (2,271m, 3,615m, and 5,200m). The case of *O2* is of special relevance since it is the legacy company of *BT Cellnet*, the first UK GSM operator, what seems to be reflected in Test1 and 2 in that 97% of their reported accuracies are either 2,271m or 3,615m (just 2 thresholds), probably indicating the use of powerful but less accurate early transmitters. Therefore, the impact of the technological network development in the accuracy of the operator seems to be another decisive factor in understanding the future usage of mobile phone location data.



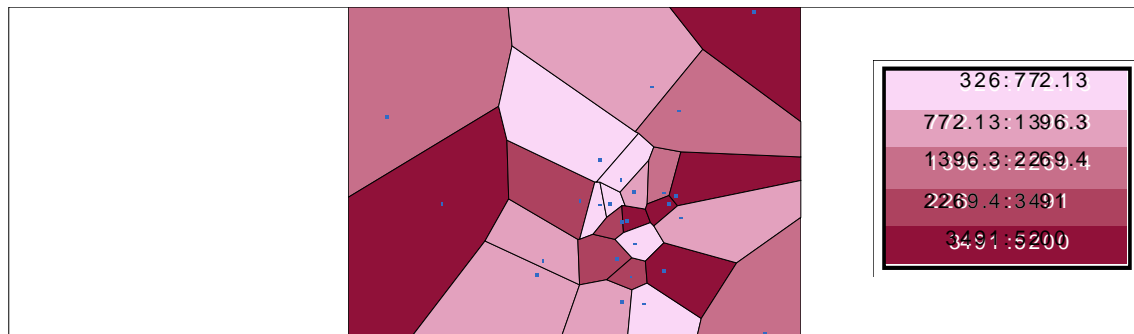
Milestones = Cells?

Even when it has been presupposed until here that the location provided with the TLS, the *milestone*, equals the location of the base station of the cell, this is not exactly true when comparing a map of TLS and base station locations from *SiteFinder*. This could be because the *milestone* is a re-calculated centroid of the cell (see Map 5.4), and

therefore there is some displacement from the base station location. The other factor could be that *SiteFinder* website is not accurately updated, but no further investigation could be done since OFCOM did not respond to the queries made to them.

Map 5.4. Voronoi Tessellation from the Milestones

Colour intensity reflects estimated accuracy (m) at each milestone/cell

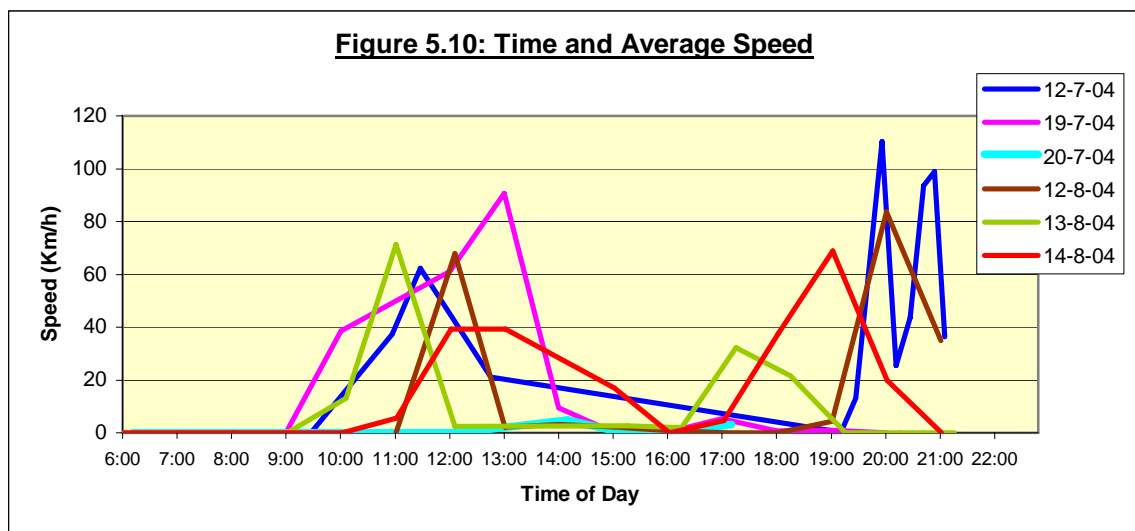


Overall, it can be concluded that the true location accuracy in Leicester city centre is 1500m at 80% of TLS and 2514m at 100%, when the reported accuracy for the same TLS were 3300m and 5200m respectively. Although this is a significant improvement for the application of the technology it is still not at all closer to the accuracy figures published in the literature. Faggion & Trocheris (2004) report it to be 500 m in urban areas, and surprisingly enough Hato & Asakura (2001), in a similar study to this research Test 2, measuring 60 TLS claim accuracies of 100m in 98% of them, and 200m in 100%.

5.3) Inter-urban mobility (Test 3)

As explained before, the aim of the last test in the research was to explore the use of mobile phone location technology in a different geographical scale; the measurement of inter-urban mobility. Such usage has proved much more useful than for intra-urban mobility due to the low geographical accuracy of the technology. The results presented here have not been analysed as much in depth as in the previous tests, since test 3 was only designed and implemented at the end of the research, but it is believed that will open new routes for further research in this direction.

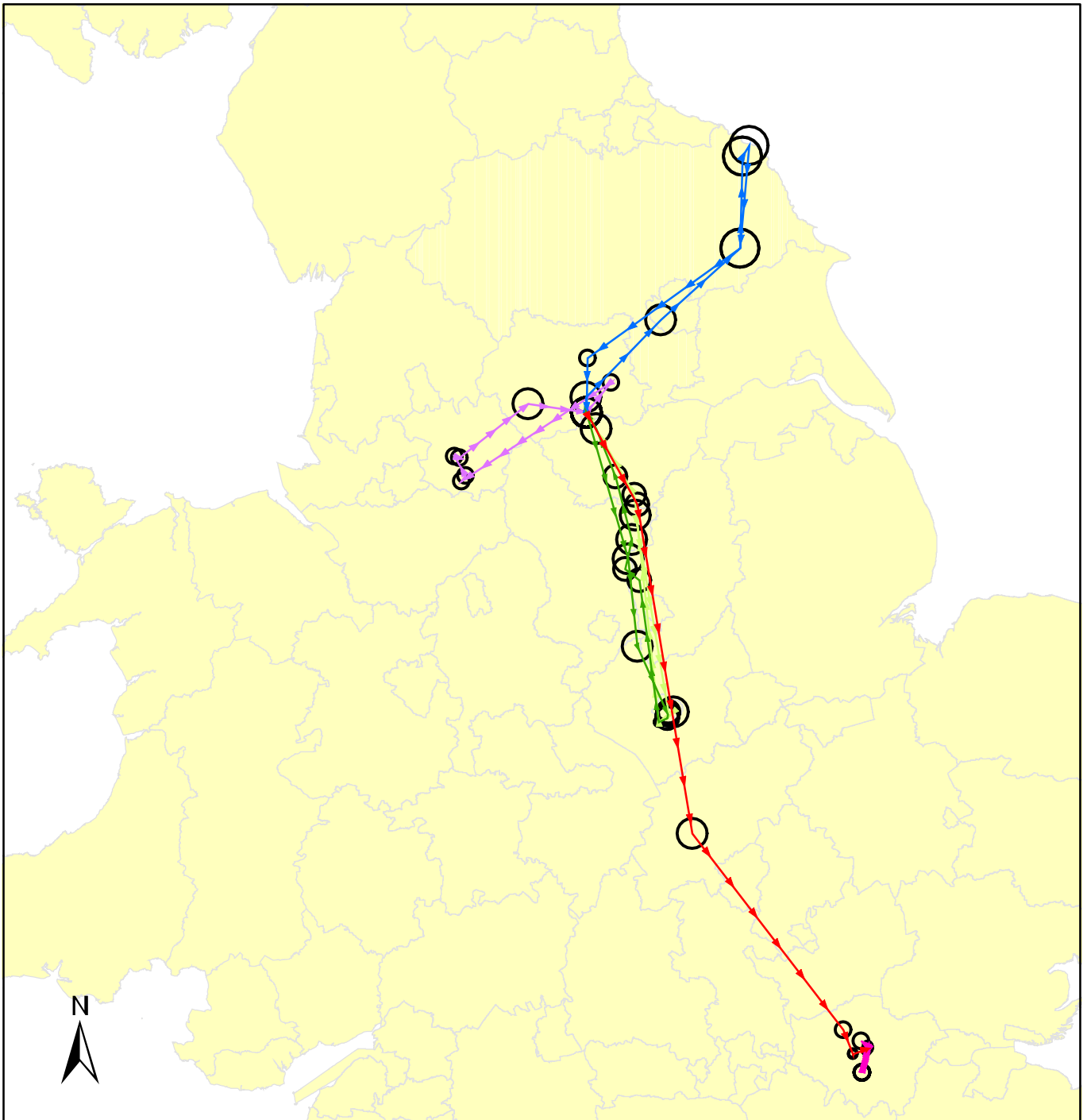
First of all, the temporal resolution of the test 3 dataset is the best of the 3 tests; TLS taken at 1 hour intervals in most of the cases¹⁷, from 6:00am to 21:00h the most frequent range allowed by *FollowUs*. Since the movements during test days were significant, the first analysis of the dataset is to calculate the distances travelled between each hourly TLS (straight line distances in this case) and then infer an average speed during that interval. Figure 5.10 shows a graph with average speeds by time of day for the 6 test days (notice that speed is not very high since it is calculated from straight line distance). Of interest is a general pattern of breakpoints in speed, such as high speed in the morning (going to different places) and similar ones in the evening (coming back from those places), except on days where a night was spent away from home (eg.19/07/04). Furthermore, breakpoints in speed can also be found for slight stops in-route (e.g. a traffic jam around 20:00h on 12/07/04). A similar type of temporal analysis has also been proposed by Dykes & Mountain (2003), who distinguish ‘temporal envelopes’ or episodes in the data from such breakpoints, as discussed in section 3.5.



But the best way to visualise this dataset is through the use of a GIS that allows to temporally link isolated time-location stamps, our TLS, such as *ArcGIS Tracking Analyst* extension. This software is intended to track moving objects like hurricanes or vehicles, although its functionality is not very flexible to perform any complex spatio-temporal analyses.

¹⁷ Except when the mobile was not available, the amount of credit in *FollowUs* was low or 2 occasions when the system failed to locate the mobile phone

Map 5.5- Test 3- Inter-urban movement tracking



0 38,500 77,000 154,000 Metres

Location Accuracy (m) ○ 4222 - 14000

○ 500 - 540

○ 541 - 1537

○ 1538 - 2401

○ 2402 - 4221

Trip Number

— 1

— 2

— 3

— 4

— 5

— 6

Map 5.5 shows that the value of the dataset resides far beyond the simple accumulation of the pure location information of each TLS, but in the spatio-temporal linkages between those time-location samples (Mountain, 2003). From the direct analysis of such linkages the following features can be derived from each pair of TLS point data; distance of movement, direction of movement (bearing), time employed to move and hence the speed of movement. When more than one pair of TLS points are considered, then the combination of potential calculations on the dataset grow exponentially, and allows the analysis of spatio-temporal behaviour (Mountain, *et al* 2001a). The analysis of such datasets have already been widely covered by the transportation literature as exposed in section 2.2.3, since they do not differ substantially from GPS collected datasets, except maybe in their lower temporal resolution.

The visualization and interpretation of inter-urban individual mobility data are not within the aims of this research. Even though, it can be mentioned that such analysis holds an enormous potential for visualising the space of flows (Castells 1996), or the liquidity of contemporary society (Sheller 2004), described in the first chapter as the current urban paradigms. Rather than trying to mathematically find patterns in these vast datasets, the most effective approach is the one proposed by Openshaw *et al* (1994), to use video visualization to try to 'see' patterns and processes by watching a movie (see section 3.5).

6) SUMMARY AND DISCUSSION OF RESULTS

The research techniques and results exposed and analysed in the last two chapters have provided a very rich empirical exploration of mobile phone location as a very relevant technology to understand individual and social mobility. This has led to the exposure of the true spatio-temporal characteristics of mobile phone location, which will be here briefly summarized and discussed.

Cellular Geography and Location Accuracy

The spatial disposition of mobile phone location's 'cellular geography' is determined by the location method used by all the operators in the UK, the basic Cell-ID method, without any slight enhancement such as Cell-ID++ (Faggion & Trocheris, 2004).

The consequence of the predominance of such method when using mobile phone location as a proxy for mobility, is a very coarse spatial resolution. Furthermore, since the accuracy estimate given by operators is always the same within a cell, this results in a discrete representation of space where the basic geographic unit is the mobile phone cell. Tracking individuals in such space requires a very different approach from doing it in the 'continuous GPS-space', but even so it offers a very easy and inexpensive possibility to visualize mobility.

The future users of this technology will have to bear in mind its restrictions in terms of location accuracy, but once understood they can find very useful applications at the appropriate geographical scales (those that allow spatial cellular units of a minimum of 3,000m radius). If the study covers a specific area where the operator has installed a number of *microcells*, such as a shopping centre, or a city centre, then smaller cell sizes can be enjoyed (500m). Nevertheless, the accuracies reported by the operators have to be taken as maximum distance from the location provided (TLS), since in almost 95% of the cases the true distance will be below it.

The research was carried out under the GSM standard (phones and network), in which different operators present a very different set-up depending in the age and type of equipment installed in their network. This fact is expected to change soon as third

generation mobile phones (3G) starts to rapidly be deployed, and will be definitely leaped forward when GPS enabled phones start to become the standard. Even today there seems to be a big difference between accuracies per country, as a result of such historical technical evolution, with the accuracies reported in Japan being much better than in the UK (Hato & Asakura, 2001)

Temporal Analysis

Time is as important as geographical position in mobile phone location. The datasets will have a concrete temporal resolution that will drive the type of applications in which it will be used. The minimum temporal resolution will be determined by the 'amount of mobility' that is to be monitored (i.e. high speed will require high temporal resolution).

Choosing a TPSP that provides the facility to place automatic location requests at certain frequencies, will enormously help the research and make its temporal coverage and temporal resolution to be consistent. Furthermore, the research found that not all the TLS are provided in real-time, but a small proportion can be 'old locations'. This can have serious consequences for some type of studies, and additional tests must be introduced to check it.

The analysis of the temporal characteristics of a dataset can offer very rich insights into the mobility patterns of the subjects of study, without the necessary need of a GIS. Even though, a GIS with temporal analysis capabilities can enrich the study, providing spatio-temporal linkages, an establishing temporal envelopes/episodes (Dykes & Mountain 2003) from temporal breakpoints in the data.

Scale of mobility analysis

The most appropriated scale to study mobility from mobile phone location data is the inter-urban mobility rather than the intra-urban movements, due to its coarse geographical accuracy. Pairs of TLS can then be analysed to calculate distance, direction, and time, and from them derived calculations such as speed, recurrence, etc.

When several pairs are connected, then inter-urban spatial patterns can start to be analysed, finding densities of relationships, directionality in time-space flows, etc. This

area falls within the subject of mobile object tracking, which has an extensive literature in computer science.

Furthermore, the current research was restricted to a very small group of individuals moving within a city, or one individual across England, but the true potential of this technology is to monitor mobility across a large group of people and even spanning to other countries. The problem of international incompatibility of mobile phone location (because it is based on single-country operator networks and national territories coverage) can be very restrictive to capture the reality of contemporary cities, with a growing proportion of international travellers becoming everyday citizens.

Visualising mobility

The visualization of vast amounts mobility flows places an enormous pressure on the creativity of visualization techniques to make sense of such data. This research has not entered into the field of geographical visualization, and instead it is suggested to draw upon mainstream research in the area of visualization of mobile objects.

Even though, some recommendations to take into consideration can be made, since mobile phone location can be best represented in a 'cell-space'. For example, the datasets can be visualized showing cell-to-cell movements, amount of change of cell, differential cell intensity, etc. Another approach is exposed by Dykes and Mountain (2002) in which density surfaces are created based on the number of occasions that a location is visited by the moving individual, and the time length of the 'stay'. This produces a classification of locations as peaks, ridges, channels or passes.

The items covered above summarize the elements that have constituted the major threats linking together the different tests and phases of the research. Many other minor aspects and related themes have risen during the trail of the investigation, but these ones have been selected for their special relevance in tackling the research questions. It is believed that they also point to in the directions where future research should be continued in this field.

In this sense, it is believed that in the future, legislation should be introduced to develop a new statistical survey effort that samples population mobile phone location data on

certain survey days. This information should be published in new aggregated ways, that follow similar guidelines as the census output area anonymity requirements, but that would allow having access to much more accurate and frequent population mobility data for researchers.

7) CONCLUSION

Mobile phones have become today ubiquitous devices that go wherever over 70% of adult population go, and therefore is an optimum probe of society wanderings. Monitoring their location in a passive way, without the need to survey the user about the meaning of their movements, provides an inexpensive and extensive technological possibility to public authorities and urban researchers interested in understanding mobility.

This dissertation has reviewed the major success factors in the application of mobile phone location as methodology to measure urban mobility trying to address all the research questions. The suitability of this technology in understanding mobility has been proved to be very relevant, due to the complexity that contemporary cities present, and that can only be reflected with representations of the 'space of flows' in which we live. However, as a result of the research and due to its low geographical accuracy, it has been found that the best scale for applying this technology is to measure inter-urban mobility rather than intra-urban flows. The technical characteristics of the mobile phone networks establish the backcloth against which the new 'cellular geography' has to be established and understood. Such a set-up, to measure and represent a massive number of individual flows, requires new spatio-temporal data models and innovative visualization techniques to be able to extract meaning from such 'space of flows'.

Finally, the challenges to individual privacy that this technology presents, require an immediate legal proposal that protects such rights at the same time that allows determined uses of this data to be aggregated following similar guidelines as the Census of Population. Failure to do so will leave room for potential abuse of this technology and the danger of it to be closed to public use, and therefore missing out the benefits for urban geographers interested in making sense of 'the elliptical world in which we now live' (Thrift, 1996, 282), with methods beyond that of standard writing.

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DEFINITIONS AND ACRONYMS

ALI: Automatic Location Information (set by FCC in the US)

ARPU: Average Revenue Per User

BNG: British National Grid

CDMA: Analogic mobile phone telephony, also known as 1st generation standard

e-911: Enhanced 911 (emergency call number in the US)

FCC: Federal Communications Commission (US)

GIS: Geographic Information Systems

GISc: Geographic Information Science

GSM: Digital mobile phone telephony, also known as 2nd generation standard

GPRS: A standard for data transmission over mobile phones, also known as 2.5 generation (between 2nd and 3rd generations)

GPS: Global Positioning System

LBS: Location Based Services

Locatee: The person whose mobile phone someone else is trying to locate

OA: Output Area – The smallest area of spatial disaggregation in the UK 2001 Census

ONS : Office for National Statistics (UK)

OFCOM: Radio and Telecommunications regulator (UK)

PLD: Personal Location Device

RF-ID: Radio Frequency Identification

TLS: Time Location Stamp, an acronym created for this dissertation (see 4.2)

TPSP: Third Party Service Provider. A company different from the mobile phone operators that provides value-added LBS services to the final user.

UMTS: A standard for 3rd generation mobile phones

APPENDICES

Appendix 1- Table of TPSPs

Appendix 2- Letters to invite participants to the mobile phone test 1

Appendix 3- Sample of TLS table

Appendix 4- Sample of FollowUS automatic location e-mail

APPENDIX 1 - LIST OF THIRD PARTY SERVICE PROVIDERS (TPSP)

Nr.	Service Name	Main Web Site	Parent Company	Address1	Address2	Address3	County	Postcode	Telephone	Telephone2	General e-mail	Contact1	Job1	e-mail 1	other comments
1	VERILOCATION	http://www.verilocation.com	Overview Mapping Ltd	Archway Offices	4-6 Church Street	Weedon	Northants	NN7 4PL	0870 4443396	01327 349878	info@overmap.co.uk	Andrew Overton	Managing Director	andrew@overmap.co.uk	VeriLocation is a new product from Overview Mapping. Overview is also an approved Ordnance Survey licenced partner
2	MAPAMOBILE	http://www.mapamobile.com	MI International Limited,	Eaglescliffe Logistics Centre	Durham Lane,	Stockton-on-Tees,		TS16 0RW	0870 121 2550	01642 881088	feedback@mapamobile.com			info@mi-int.com	
3	PHONETRACK	http://www.phonetrack.net/	AffinityOne Group	4G Beaumont House	Sutton Road	St Albans	Hertfordshire	AL1 5HH	08709 220 770		info@phonetrack.net			Info@affinityone.co.uk	
4	TRACE A MOBILE	http://www.traceamobile.com	VR MEETING LIMITED		27, Mortimer Street,	London		W1T 3BL							(Company number 03911353)
5	LOCATE MOBILES	http://www.locatemobiles.com	VR MEETING LIMITED		27, Mortimer Street,	London		W1T 3BL							
6	PINPOINTERS	http://www.pinpointers.com/								t:+44(0)1202 496694	info@pinpointers.com				Uses GPS enabled phones. Solution aimed at professional markets
7	MAPAPHONE	www.mapminder.co.uk	Mapbyte Ltd	Middlesex House	34-42 Cleveland Street	London		W1T 4LB	Tel: +44 (0)20 7323 0323	Fax: +44 (0)20 7580 1938	customerservices@mapminder.com			info@mapbyte.com	Mapaphone is a service within mapminder offering state-of-the-art mobile phone location on the map. Mapminder is published by Mapbyte Limited
8	CHILDLOCATE	http://www.childlocate.co.uk/	MobileLocate Ltd	ChildLocate	6 Pound Street	Newbury	Berkshire	RG14 6AA	Tel 0870 44 500 55 / 66	Fax (Reception): 01635 522 212	support@childlocate.co.uk	Jon Magnusson	Managing Director		Owned by TrackWell an Icelandic company http://www.trackwell.com e-mail: info@trackwell.com
9	FOLLOW US	www.followus.co.uk		Europa House	Church Street	Old Isleworth	Middlesex.	TW7 6DA	Sales : 087171 77 234	Fax : 0870 429 2712	sales@followus.co.uk	Martin Pinnel-Brown	Managing Director		Second Address at PO Box 730, Luton Bedfordshire. LU1 4ED
10	FONETRACK	http://www.justfone.com/corp/fonetrack.html	JustFone, UK	Tweed Horizon Centre	Newtown St Boswells	Melrose	Roxburghshire, SCOTLAND	TD6 0SG	Tel: +44 (0)8707 706968	Fax: +44 (0)1835 826401	Email: info@justfone.com				
11	WAYHEY	http://www.wayhey.com/	WayMobile Ltd	Office C Maple Barn	Buckham Hill,	Uckfield,	East Sussex	TN22 5XZ			email: info@way-mobile.com				
12	WHERE RU	http://www.where-ru.com/	Where RU Ltd.		119 - 121 Canal Street,	Nottingham		NG1 7HB	0115 9419830						Company Reg No 4845035

Appendix 2- Letters to invite participants to the mobile phone test

From: Mateos, P.

Sent: Tue 6/8/2004 5:31 PM

Subject: Mobile Phone Test Instructions

Hello to all,

Thanks for agreeing in participating in the test that I am doing for my dissertation on mobile phone location. Finally I registered you today in the service (or are about to do so). You should have already received an SMS text message with a message inviting you to join the service.

The service provider I am using is called 'Child Locate' but it also locates other people (not only children!).

All you need to do when you receive this message is reply to it (to phone number 85239) with the following text:

LOC YES 07xxxxxxx (Your mobile phone number)

This message will only cost you the same as any normal text message with your phone. As I said the location accuracy is well beyond 100 mts, so for example I am locating right now myself to the University Library and at the map I attach you can see me in Victoria Park. The purpose of the test is to aggregate individual movements into overall flows, so that privacy is maintained.

I will produce my own maps of overall movement flows.

Thanks a lot for participating in this test. I will notify you when I unsubscribe you to the service and will send you some feedback on how the test went. If you still now of anyone interested please let me know, we can also test it any other week as long as the person is still based in Leicester.

Regards, Pablo pm99@le.ac.uk

From: Mateos, P.

Sent: Fri 5/28/2004 1:31 PM

Subject: Proposal to collaborate in a Test for Dissertation

Dear all,

I am writing to you to ask you for help in getting people to participate in a test that I am designing for my dissertation, that as you might remember is called something like "*Mobile Geography; Understanding urban mobility through location based services*".

I need to do a test with at least 10 people that have a UK mobile phone and live either in the student residence of Opal Court (new blue/white big building next to the fire station) or in the immediate nearby area (around 1 km radius). This is to ensure we only study the population based in one Output Area. The test will take place on the week starting Monday 7th of June. I know that only very few of you live in this area, but I would like you to forward this mail to any person you know that lives in the area.

=====DESCRIPTION OF THE TEST AND HOW TO PARTICIPATE=====

The test will consist in that I will request to know the position of your mobile phone a few times (6 to 8) during one or two days (you will know when). From your side it will be a totally passive participation, and you will only need to respond to an SMS text message, only one time, confirming that you agree with me requesting your position to the service provider. There is no cost at all for you and you will be notified that I have removed you from the service when the test is finished. All the data will be treated with absolute confidentiality, your phone number will be immediately removed (I will replace it with a sequence number) and not appear anywhere in my study. Since all of you participating will have to live in Opal Court or nearby area, the maps will aggregate the positions of all you at the origin without being able to know who is who. I will send you more details if you agree to participate, and of course answer any other question you may have. As a reward to your participation I can only offer you a copy of my final dissertation, should you be interested in the study.

How can you help me? If you would like to participate and help me with my dissertation, you must first check if you comply with the following requirements:

- You should have a mobile phone with a UK number under one of these operators: O2, T-Mobile, Orange, or Vodafone
- You should either live in Opal Court or in an area nearby, such as student houses around Museum Studies
- You will have to be in Leicester one or two days in the week commencing on Monday 7th of

June.

If you are OK with these three things and would like to participate, please respond to this e-mail filling in the following information:

- Your Mobile phone number:
- Your Operator (delete as appropriate): O2, T-Mobile, Orange, or Vodafone
- Days of the week in Leicester (delete when not in): June=> Mon 7, Tue 8, Wed 9, Thu 10, Fri 11, Sat 12, Sun 13

I would also like to ask you to please forward this mail to any other person that lives in Opal Court and might also be interested.

Thank you very much for reading this and hope that you could help me with this test which will be key to my project.

Pablo Mateos

pm99@le.ac.uk

Appendix 3- Sample of TLS table

ID	Name	Date_	Loc_Attempt_Time	Status	Map_Time	Date_Time	Accuracy_mts_	Mast	Operator	Eastings	Northings
148		08-Jun-04	12:33		12:33	6/8/2004 12:33	2271	LeicStationO2	O2	459300.212	304046.084
147		08-Jun-04	16:43		16:42	6/8/2004 16:42	2271	NatWestUniPark	O2	459480.755	302838.285
19		09-Jun-04	11:24		11:23	6/9/2004 11:23	5200	LeicStationVodafone	Vodafone	459386.038	304052.192
140		09-Jun-04	11:30		11:28	6/9/2004 11:28	5200	ClaredonQueens	Vodafone	460212.196	302949.874
50		09-Jun-04	11:35		11:34	6/9/2004 11:34	500	NatWideMillhouse	Vodafone	459032.887	304462.085
86		09-Jun-04	11:52		11:51	6/9/2004 11:51	1304	EastParkBonsall	Orange	460563.806	304133.791
68		09-Jun-04	12:03		12:02	6/9/2004 12:02	5200	Sky	Vodafone	460462.769	304620.518
104		09-Jun-04	12:08		12:07	6/9/2004 12:07	800	StMathewsALDI	Vodafone	459559.807	304708.472
122		09-Jun-04	12:12		12:11	6/9/2004 12:11	5200	Sky	Vodafone	460462.769	304620.518
18		09-Jun-04	12:19		12:18	6/9/2004 12:18	5200	LeicStationVodafone	Vodafone	459386.038	304052.192
49		09-Jun-04	12:31		12:29	6/9/2004 12:29	1200	StRichardNarborough	Vodafone	457578.762	303202.024
139		09-Jun-04	12:34		12:33	6/9/2004 12:33	5200	ClaredonQueens	Vodafone	460212.196	302949.874
146		09-Jun-04	12:41		12:40	6/9/2004 12:40	2271	LeicStationO2	O2	459300.212	304046.084
145		09-Jun-04	12:47		12:46	6/9/2004 12:46	2271	NatWestUni	O2	459161.021	303220.224
85		09-Jun-04	13:27		13:08	6/9/2004 13:08	1304	Bishop2Kaouru	Orange	459301.279	302313.009
67		09-Jun-04	13:23		13:21	6/9/2004 13:21	1700	MercuryBelvoir	Vodafone	460542.205	306509.583
103		09-Jun-04	13:32		13:31	6/9/2004 13:31	1900	Sky2	Vodafone	460215.04	304692.339
121		09-Jun-04	13:36		13:35	6/9/2004 13:35	5200	ClaredonQueens	Vodafone	460212.196	302949.874
48		09-Jun-04	13:39		13:38	6/9/2004 13:38	1200	StRichardNarborough	Vodafone	457578.762	303202.024
144		09-Jun-04	13:43		13:42	6/9/2004 13:42	2271	LeicStationO2	O2	459300.212	304046.084
17		09-Jun-04	13:46		13:45	6/9/2004 13:45	5200	ClaredonQueens	Vodafone	460212.196	302949.874
138		09-Jun-04	13:51		13:50	6/9/2004 13:50	5200	ClaredonQueens	Vodafone	460212.196	302949.874
143		09-Jun-04	13:55		13:54	6/9/2004 13:54	2271	LeicStationO2	O2	459300.212	304046.084
142		09-Jun-04	14:14		14:14	6/9/2004 14:14	2271	Thrifty	O2	458378.054	304530
141		09-Jun-04	14:32		14:32	6/9/2004 14:32	2271	Thrifty	O2	458378.054	304530

Appendix 4 - Sample of FollowUS automatic location e-mail

-----Original Message-----

From: Follow Administrator [mailto:automated.message@followus.co.uk]

Sent: 12 August, 2004 11:01

To: mateospablo@yahoo.es

Subject: Yo Thu Aug 12 11:01:07 BST 2004 Automated location

Dear Pablo Mateos,

Here are the results for the automatic location of handsets that you configured for group: **Yo** You can change your automatic location configuration options for this group online at <http://www.followus.co.uk> by logging into your account, selecting the group **Yo** from the groups list, and clicking on the '**Auto Locate**' button.

Happy Locating,

FollowUs Customer Care

Location results for mobile asset	Yo (447843447326) Near Barlborough, Chesterfield Derbyshire S43
Location request processed at	Thu Aug 12 11:01:07 BST 2004
Location was accurate at	12/08/2004 11:04
Other information:	
Transmitter X co-ordinate (OSGB)	447303
Transmitter Y co-ordinate (OSGB)	376066
Proximity from transmitter (Metres)	3500
Postcode	S43
Area map	Click here