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ABSTRACT: The technology for determining the geographic location of cellphones and other hand-held devices is becoming increasingly available. It is opening the way to a wide range of applications, collectively referred to as Location Based Services (LBS), that are primarily aimed at individual users. However, if deployed to retrieve aggregated data in cities, LBS could become a powerful tool for urban cartography. This paper describes preliminary results of the "Mobile Landscapes: Graz in Real Time" project, which was developed as part of the M-City exhibition (Graz Kunsthaus, 1 October 2005 – 8 January 2006, curator Marco De Michelis), in collaboration with the cellphone operator A1/Mobilkom Austria. Three types of maps of the urban area of Graz, Austria, were developed and shown in real-time on the exhibition premises: cellphone traffic intensity, traffic migration (handovers) and traces of registered users as they move through the city. Beyond their novelty and visual interest, results seem to open the way to a new paradigm in urban planning: that of the real-time city.

1 Introduction

The mobile communications industry is booming. Cellphone subscriptions have recorded sustained growth rates in recent years and, according to EITO (2004), reached the astronomic figure of 350 million in Western Europe in 2003 (157 million in the USA).

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

Locational data are becoming increasingly available and their applications are currently a hot topic in the cellphone industry (see for instance www.lbszone.com). They are generally referred to as Location Based Services (LBS) – value-added services for individuals in the form of new utilities embedded in their personal devices. Examples, both implemented and speculative, include systems providing information about one's surroundings (nearby restaurants, museums, emergency shelters, and so on); distributed chat lines aimed at allowing people with similar profiles to encounter each other in space, via a kind of technologically augmented serendipity; and 'digital tapestries' that attach different types of information to physical spaces (see sections below for detailed references). And yet, surprisingly enough, aggregated locational data have not been used to describe urban systems. Research efforts in the area are sparse; the scientific literature mostly ignores themes such as the mapping of the cellphone activity in cities or the visualization of urban metabolism based on handset movements (a notable exceptions are the work of Ahas and Ülar, 2005 and Ratti *et al.*, 2005). How could this be?

We try to guess. The first assumption is that scholarly research has been hampered so far by the difficulty of accessing raw data and developing ad-hoc analysis software and systems in partnership with cellphone companies. The second reason could be traced back to the lack of rules for managing these data and to the increasing privacy concerns that are being raised, often resulting into a situation of stall. In this study, the research team has had the opportunity to establish a partnership with the mobile network operator A1/Mobilkom Austria, which has the largest market share in its own country. Thus, a privileged insight into how aggregated data from mobile devices could reveal urban systems was gained. Furthermore, the occasion of the project was developed in the context of a public architecture and art event, the M-City exhibition (Graz Kunsthaus, 1 October 2005 – 8 January 2006, curator Marco De Michelis). Such a premise seemed ideal in order to remove suspicions of possible privacy abuse and openly engage the public in the issues related to locational data and the way they should be used.

As the exhibition is in progress, only some preliminary results are presented here. Further analyses will be performed in the coming months. However, results seem to open the way to a new approach to the understanding of urban systems, which we have termed "Mobile Landscapes." Mobile Landscapes could give new answers to long-standing questions in architecture and urban planning: how to map vehicle origins and destinations? How to understand the patterns of pedestrian movement? How to highlight critical points in the urban infrastructure? What is the relationship between urban forms and flows? And so on. More generally, information and communication technologies, which previously eluded planners with their "invisible, silent" characteristics (Graham and Marvin, 1996), are becoming of increasing interest. Studies on user behavior (for example Charlot and Duranton, forthcoming; Hampton and Wellman, 2000; Gaspar and Glaeser, 1996) are showing that "electronic communications" and the "metropolitan area […] are actually supporting each other" (Graham, 2004). The aim here is to expand upon these methods by integrating a spatial component to visualize telecommunications. Thus, the objectives of our maps are twofold: first, they enable viewers to visualize the city via an otherwise "invisible" feature; second, the maps are animated in a way that can simulate city dynamics in real time.

In a previous paper (Ratti *et al.*, 2005) we have shown how even simple data such as network traffic have a lot to offer to the urban designer or planner. We will describe here how some more complex types of data can be obtained to produce real-time urban maps. In particular, three type of data are provided by the mobile network, namely cellphone traffic intensity, traffic migration (handovers) and traces of registered users as they move through the city.

2 The data

Mobile communication networks are organized in cells. Each cell has an antenna that covers a certain geographical area (usually circular or pie-shaped) and offers mobile communication services to users at that particular location. In the most-common GSM networks, cell sizes vary from the diameter of about 100-300 meters in urban areas to several kilometres in rural areas. Densely inhabited areas require smaller cell sizes, as the maximum amount of data that can be transferred concurrently in one cell is limited and relates to the radio access technology of the network.

Figure 1 shows the basic components of a GSM network and the data flow that was implemented for the Mobile Landscape Graz project. A Mobile Switching Center (MSC) is connected to several Base Station Controllers (BSC). The BSCs control the Base Transceiver Stations (BTS). The Base Transceiver Station houses the radio transceivers that define a cell and handles the radio-link protocols with the Mobile Equipment (ME). The movement of a mobile phone from one cell to another is called 'handover'.

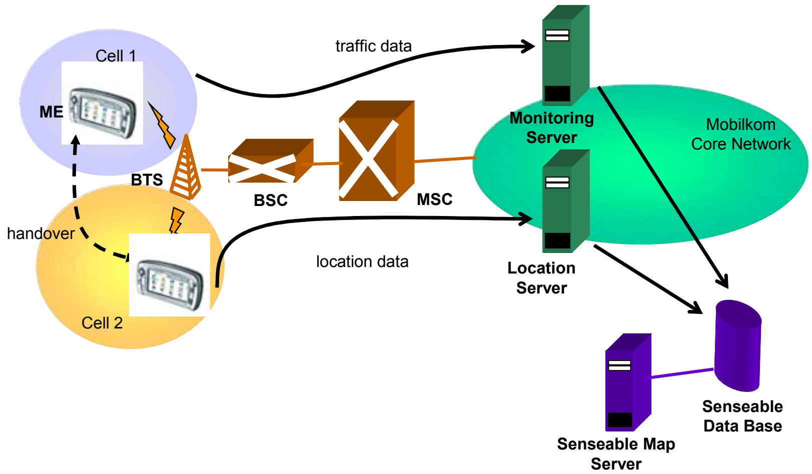

Figure 1: Data flow in the project M-City

Traffic in the cells of the A1/Mobilkom Austria network is constantly monitored by the Operation and Maintenance division and aggregated performance figures are logged by a Monitoring Server. For the Mobile Landscape Graz project the traffic of all cells in the city of Graz was measured periodically and traffic aggregates where reported at regular intervals to an online database set up by the MIT SENSEable City Laboratory. Traffic intensity of one cell is measured by the number of calls that originate there and by the occupancy of the cell measures in Erlang, a standard unit of measurement of traffic intensity in a telecommunications system (one Erlang is the equivalent of one caller talking for one hour on one telephone or two callers talking for 30 minutes each).
Table 1 shows a sample of traffic intensity data, where BSC is the name of the Base Station Controller, FZA is an identification of the Base Transceiver Station, CI is the cell ID, TCH_ATT gives the number of traffic channel attachments including handovers, Erlang gives the occupancy of the cell and CALL_REQ gives the number of originated calls.

int_id	PERIOD_START_TIME	BSC	FZA	CI	TCH_ATT	ERLANG	CALL_REQ
792903	2005-10-08 05:30:00	Graz_4	G285-1	28516	8	0.13	4
793754	2005-10-08 06:30:00	Graz_4	G285-1	28516	8	0.40	3
794605	2005-10-08 07:30:00	Graz_4	G285-1	28516	38	0.89	17

Table 1: Traffic intensity data sample

Traffic migration is measured by the number of active calls that move from one cell to another and is reported to the SENSEable City Laboratory by giving the number of incoming and outgoing handovers between cell pairs.
Table 2 shows a sample of the traffic migration data where the number of inbound and outbound handovers (HO_in, HO_out) are given for source and destination cells (Source_CI, Dest_CI).

int_id	PERIOD_START_T	Source_BSC	Source_FZA	Source_CI	HO_out	HO_in	Dest_CI
7089747	2005-10-10 10:00:00	Graz_1	G200-2	20026	3	4	58236
7089746	2005-10-10 10:00:00	Graz_1	G200-2	20026	2	13	43130
7089745	2005-10-10 10:00:00	Graz_1	G200-2	20026	10	25	43110

Table 2: Traffic migration sample data

Traffic intensity and traffic migration are aggregate figures that show in real time where people started their mobile phone calls, how long they talked and where they were moving while talking. The third type of data that was shown on the maps at the M-City exhibition was the movement of individual users. While the measured traffic aggregates collect only data about active phone calls, a cellular network is also able to locate passive mobiles in order to set-up calls towards them. This process is called 'paging' and can also be used to request the ID of the cell to which the mobile phone is attached, even if no call is being made. Based on the cell ID, geographical coordinates can be obtained, corresponding to the central point of the GSM cell where the user is attached to the network. Movement tracks can thus be generated by locating the user at regular 5-minute intervals.

A note should be made, however, on the treatment of location data. On the one hand they can be of considerable value to information and communication services. On the other hand, however, they raise privacy issues; users are concerned about revealing their position data to others, especially to un-trusted third party applications. Furthermore, most countries have legal restrictions that regulate processing of personal data and the protection of privacy in electronic communications. It is of utmost importance that the users can control who gets access to their location data and that the transport in the network of such sensitive data is protected by strong security mechanisms.

The Mobile Landscape Graz installation pays respect to privacy concerns by giving users full control over the location service. Only volunteers are tracked and they have to subscribe actively to the service by sending a short message (SMS), where they can also provide a pseudonym (nickname) that is shown on the map. If no pseudonym is provided, a random one is generated. The user can stop the location application at any time by simply sending a second SMS to the subscription application. Even if no second SMS is received, the application stops locating users after 24 hours. Location data is sent to the SENSEable City Laboratory via an encrypted connection and it contains only users' pseudonyms.

Table 3 shows a data sample where the geographical coordinates in latitude and longitude are given for several pseudonyms at regular intervals.

nick	**latitude**	**longitude**	**timestamp**
Sabine	47.06354	15.454447	20051009-14:32
User940	47.06354	15.454447	20051009-14:32
Wort	0.0	0.0	20051009-14:32
Nyko	47.05407	15.462827	20051009-14:32
OrangeMo	47.10022	15.397057	20051009-14:32
User3346	47.09155	15.7262	20051009-14:32

Table 3: User movement sample data

3 The real-time mapping system

A common procedure has been developed for all data types presented above (cellphone traffic intensity, traffic migration and traces of registered users as they move through the city) in order to produce real-time maps at the exhibition premises. Records are collected live by A1/Mobilkom Austria and sent to an ad-hoc set up server at MIT, where they are stored in an open-source MySQL database. The data is then paired using ArcGIS with spatial information on the city of Graz, generously provided by GIS Steiermark (www.gis.steiermark.at). Finally, the whole process is animated using Macromedia Flash. A diagram of the process is shown in Figure 2.

A note should be made on the procedure and on the choice of using Flash. Streaming real-time animations from the MIT SENSEable City Laboratory to the exhibition venue would have been too costly in terms of bandwidth and also unreliable. Flash allowed high

compatibility interface, running on most Internet browsers, and also the transfer of a limited amount of data. In the case of the Erlang map, just a maximum of 24 images were transferred from SENSEable City Laboratory and then animated in Flash. In the case of the two other maps, a Flash algorithm running at the exhibition venue retrieved automatically the data from the MySQL database to create the required animations, as detailed below.
Options other than Flash were tested, but did not prove satisfactory. Adopting ArcGIS to produce the animations would have required end users to have a GIS viewer – thus limiting the distribution of the images. Options for producing maps on the web without end-user software were also considered, such as Mapserver and ArcIMS; however, both technologies did not have the ability to reproduce the real-time feel of animated images and lacked the graphic qualities we were aiming for.

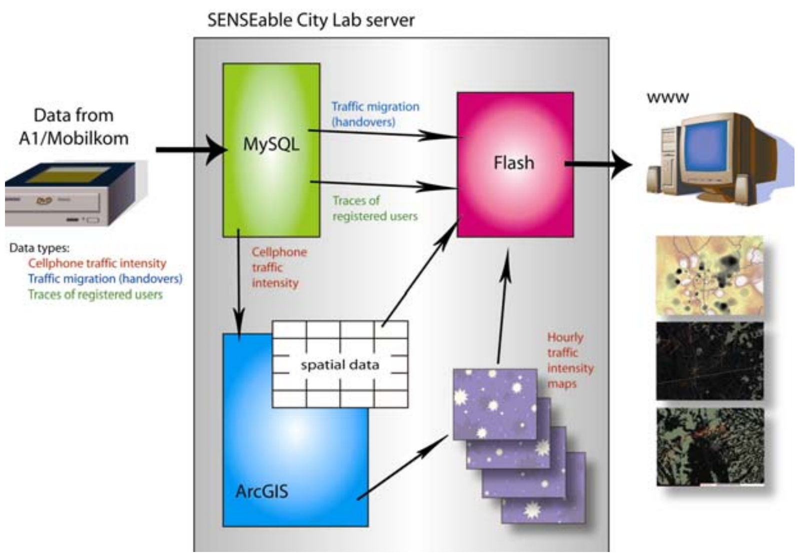

Figure 2: Data flow from the SENSEable City Laboratory server to the final maps

4 The results

This paper presents work in progress, as the Mobile Landscape Graz project is being exhibited; data acquisition will continue until January 2006 and a larger interpretative effort is planned afterwards. However, this section of the paper presents the maps that are being produced and discusses their meaning.
Using the three types of data transferred by A1/Mobilkom Austria to the SENSEable City Laboratory, three different real-time maps of Graz were obtained: cellphone traffic intensity, traffic migration (handovers) and traces of registered users as they move through the city. These maps visualize different states of cellphone activity in Graz and the emergent movement patterns of cellphone users throughout a day. Our aims were manyfold: first, by cartographically illustrating the raw cellphone traffic data, we were trying to visualize dynamic layers of information, which tend to remain transparent in everyday life. Second, we were trying to use cellphone information as a substitute for other urban information, thus visualizing the city as a real-time, pulsating entity. Third, we were trying to display different types of sensitive information, such as location data, in order to engage the public in the discussion on how it should be treated in the coming years.
More details follow on the three different types of maps, presented in Figure 3.

4.1 Cellphone traffic intensity

The Erlang map shows the most recent distribution of cellphone traffic intensity in Graz. It is animated in such a way to play through a three-minute visualization of the last 24 hours. The data shows total Erlang values of each A1/Mobilkom Austria cell antenna, interpolated using the color-field intensity map shown in the lower right corner of the image. Light and pink colors stand for higher intensity, and green and black for lower or zero intensity respectively. A street and river map of Graz is overlaid on top of the interpolated graph in order to provide location references for exhibition visitors.

4.2 Traffic migration

Similar to the Erlang maps, data is received at hourly installments and then animated in an accelerated way over 15-minute cycles. For each handover, a dynamic orange line is drawn using Flash between its origin and destination. If several handovers happen between the same pair of cells, several lines are drawn over the same trajectory. Already drawn lines slowly fade away in order to make new ones more visible. The animation renders all the phone-calls of a randomly chosen cell in a sequence and then jumps to another cell. This is why star-like shapes appear on the map - a star representing the total incoming and outgoing calls of a given cell. If the origin and destination of a handover lie outside the visible area of the map, then the call is still mapped as a thoroughfare orange line. At the end of a 15 minute cycle, the total activity graph of the last hour becomes visible.

4.3 Traces of registered users

This map allows individual A1/Mobilkom Austria clients who have registered to have their cellphone tracked on the map. The registration process happens by sending an SMS to an activation number. From that moment onwards, the selected nickname of the user appears on the map and her/his position is followed at five-minute intervals. A user can also stop being tracked anytime, by sending a “stop” message to the same number; alternatively, he/she will be automatically withdrawn after 24 hours. Traces are visualized as orange lines on the map, showing movements during the past 24 hours. In order to be able to differentiate between different paths on a complex background generated by multiple user, the following procedure was implemented: one after the other, paths are highlighted in red and scanned by a white ball which replays the past 24 hours, while the nickname of the corresponding user is shown on the lower left corner of the screen.

Figure 3: From left to right: visualization of cellphone traffic intensity on 10 October 2005 at 8 pm; visualization of traffic migration (handovers) at the same time; traces of registered users at the same time. During the exhibition period these maps can be seen in real time at the URL: http://senseable.mit.edu/grazrealtime

4.4 Discussion

The maps produced in partnership between A1/Mobilkom Austria and the SENSEable City Laboratory proved to be successful in visualizing the city of Graz in almost real time. This proof of concept seemed quite important, as no similar precedents based on cellphone mapping are found in the scientific literature.

The work also managed to capture wide interest at the exhibition in the Kunsthaus Graz as well as on-line and in the press (some of the published articles and discussion can be found at the URL: http://senseable.mit.edu). Visitors in Graz seemed highly interested in seeing their home-town represented in a new, intangible way and were keen on testing the tracking system to follow their own or their friends' traces. Many reviews on the project also confirmed both the lack and necessity of such cartography to add to our urban knowledge.

The public appearance of the project also brought up many discussions about privacy concerns. Even if they were not so extreme as the 'Geoslavery' fears voiced by Dobson (2003), before the official opening of the exhibition 'big brotherish' comments appeared amongst participants and in the media. However, as privacy procedures were thoroughly respected at every step of the project and individual tracking could only happen on a voluntary basis, none of these points became detrimental. Conversely, they contributed in a certain sense to one of the aims of the project: presenting this new type of sensitive information in order to prompt a discussion on how it should be used.

Practical application for the analysis of the data will be discussed once the exhibition is over. In a previous paper (Ratti *et al.*, 2005), we have shown that even simple cellphone traffic analysis can contribute exceptionally to urban analyses. More generally, there seems to be a large gamut of interests, ranging from the enrichment of people's understanding about urban communications to the unprecedented collection of real-time data about cities (see William Mitchell's (2005) review of the Mobile Landscape Graz project, 'The Real Time City').

Finally, it is worth mentioning some limitations of our process. First, as mentioned above, the accuracy of phone call and user locations are estimated using the latitude and longitude coordinates of cells. This means that the larger the diameter of the cell, the less accurately we can determine the user's exact position. Furthermore, users that are roughly equidistant between two cell antennae may have their signals picked up by either of them, sometimes even bouncing between cells. The bouncing phenomenon can be observed on our traces map: sometimes static users appear to move back and forth repeatedly between neighboring antennae.

Finally, the Flash software lacks ArcGIS's precision to convert geographical coordinates to pixel-based screen coordinates. Although we kept data in ArcGIS for as much of the procedure as possible, the final representation in Flash introduces some distortion in the mapping. This was acceptable in the context of the exhibition, but might require a different treatment in future quantitative analyses.

A last note on the notion of 'real time': while data were collected instantly by the network operator, their transfer to the SENSEable City Lab server was aggregated at 5-minute to 1-hour intervals. This was done to optimize bandwith and processing power, though the same system that was set up could theoretically withstand second-long (or less) frequencies.

5 Conclusions

This paper reports on the Mobile Landscape Graz project, developed by the MIT SENSEable City Laboratory in collaboration with A1/Mobilkom Austria as part of the M-City exhibition (Graz Kunsthaus, 1 October 2005 – 8 January 2006, curator Marco De Michelis). The different types of data (section 2), the procedure set up to transfer them in real time (section 3) and the resulting maps (section 4) are described above and commented. While a larger interpretative effort is planned after the completion of the exhibition, preliminary results suggest that the mapping of cellphone data could open unprecedented perspectives in urban cartography and lead to a new urban paradigm: that of the real time city.

6 Acknowledgements

First, we would like to thank all of the SENSEable Graz team: Daniel Berry, Daniel Gutierrez, David Lee, Xiongjiu Liao, Jia Lou, Andrea Mattiello, Eugenio Morello. They are the ones who made this project happen! Acknowledgements go to 'M-City' curator Marco de Michelis and all of the people at the Graz Kunsthaus (in particular, Peter Pakesch, Sabine Suppan and Katrin Bucher). Also, the project would not have been possible without the generous support of A1/Mobilkom Austria, who provided us with the data and worked closely with our team. Their continuing involvement, that extends till the phase of writing this paper, proves their farsighted commitment to academic discovery and policy-making. Finally, the results reported in this paper are part of a broader research effort on the use of new technologies to describe cities. We are indebted to many people at the Massachusetts Institute of Technology, Cambridge, MA, for providing an extremely stimulating research environment and for their generous feedback; amongst others: Eran Ben-Joseph, Joseph Ferreira, Dennis Frenchman, Hiroshi Ishii, Frank Levy, William Mitchell, George Stiny, and Lawrence Vale. Janet Owers, based in the 'real' Cambridge (UK), provided expert editorial guidance. Of course, any shortcomings are our sole responsibility.

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