

Chapter XXII

Mapping the MIT Campus in Real Time Using WiFi

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ABSTRACT

This chapter presents the iSPOTS project, which collects and maps data of WiFi usage on the Massachusetts Institute of Technology campus in Cambridge, Boston. Instead of simply mapping the locations of WiFi availability, the project is possibly the first to use and analyze log files from the Institute's Internet service provider and to produce spatial visualizations of the observed activity in real time. The aim is to create a better understanding of the daily working and living patterns of the MIT academic community, which changes due to the emergence of WiFi itself. The MIT wireless IEEE 802.11 network, consisting of 3,000 access points (one of the largest of its kind) offers a privileged environment for this research and, in perspective, can provide a test bed for entire cities.

INTRODUCTION

Recent years have witnessed a great increase in wireless Internet access points (WiFi hotspots) in cities around the world. As of the end of 2007, there were over 67,000 public hotspots already available in the U.S. (JWire, 2007), roughly doubling every year. With several forward-looking cities like Boston, MA, San Francisco, CA, and Philadelphia, PA, have launched projects to provide city-wide wireless Internet access for all citizens (cf. Forlano in this volume), WiFi is becoming as common in urban areas as traditional public utilities, such as electricity and land-line phones. The popularity of WiFi is further enhanced by its capacity to communicate multiple types of media over the same protocol: text, voice, images and video can all be streamed over wireless networks instantaneously and globally. As ubiquitous WiFi coverage might be appearing in many cities¹, we see an urgent need to explore the spatial impact of this powerful new communication network from the point of view of an urban planner or architect.

A number of studies have been done to describe WiFi signal availability and intensity in geographic context (see for instance Skyhook, <http://www.skyhookwireless.com/>). A culture of so-called WiFi ‘sniffing’ has developed in recent years, which is often related to the mapping of public wireless networks on web pages (e.g., JWire, 2007, the global hotspots finder) ‘wardriving’ (mapping wireless networks by driving in a car equipped with a sniffer device) and ‘warchalking’: the drawing of symbols in public places to advertise open wireless Internet networks. Several computer science and engineering studies have used wireless log information to analyze and quantify network traffic to answer questions about network optimization, load balance, and the like (Kotz & Essien 2005). However, there have been few attempts to analyze spatial patterns of traffic on large WiFi networks through log information from Internet Service Providers (ISPs). The lack

of such studies can possibly be attributed to the difficulties of accessing raw Internet traffic data and combining it with geo-spatial databases. In the iSPOTS project, carried out by the SENSEable City Laboratory at MIT in collaboration with MIT Information Services and Technology (IS&T), we have had the opportunity to access such data and to provide on-line visualizations of its spatial distribution to the public. A real-time system was set up to gather, process, and visualize the data on the campus map, allowing the MIT community to view and act upon the information instantaneously. A description of the project, including its architecture and preliminary results, is presented below.

The remainder of this chapter is structured as follows. Section 2 provides the background and some key pieces of work related to our project. Section 3 provides background on the MIT campus and network environment. Section 4 describes the data infrastructure, and Section 5 describes our data processing methods. We discuss the weaknesses of our current setup and prescribe directions for future work in Section 6 before concluding.

CONTEXT

A series of campus-wide WiFi studies during early 2000 has paralleled the ongoing transition from fixed wire accessibility to ubiquitous WiFi environment. Some of the most comprehensive of these studies were done in Dartmouth College (Henderson, Kotz & Abyzov 2004, Kotz & Essien 2002, Kotz & Essien 2005). Within the past years the usage of campus WiFi has increased as more people have adopted WiFi-enabled laptops, as well as other WiFi clients such as PDAs and VoIP devices. However, the proportion of WiFi users at popular buildings, in libraries and classrooms appeared to be consistent from the years 2001 to 2004. A similar pattern of preferred WiFi location usage was observed at the University of

Saskatchewan in Canada (Schwab & Bunt 2004). The evidence from these studies was inconclusive regarding types of Internet based activities the users engaged in at these locations. An earlier study at Stanford (Tang & Baker 2002) found that the activities performed while connected to the wireless network varied from person to person, involving both work and leisure communication activities (email and instant messaging). At the University of North Carolina, Chinchilla, Lindsey & Papadopouli (2004) found that users accessed similar web content regardless of their location.

The main purpose of the studies above was to characterize network performance and WiFi users' individual exploitation of the network. Another relevant group of studies revolves around the technologies for indoor positioning. WiFi-based positioning, sometimes called WPS for WiFi Positioning System (Schilit et al. 2003), have been explored by Balazinska & Castro (2003) for locating users by building. Other location systems based on indoor sensor networks include Cricket, an economical yet highly accurate system for indoor navigation (Priyantha et al. 2003), and wireless motion sensors deployed in the Mitsubishi Electronic Research Laboratories building with more intelligent algorithms to determine what movements actually correspond to human presence in spaces (Wren et al. 2006).

The iSPOTS system is applied over the entire MIT campus (with a few exceptions described in the following section) covering thousands of individual room locations. The large amount of data collected, characterized by a predetermined distribution of access points based on the original assigned use of space (e.g. classroom, hallway, residence, etc.) can inform space planners about the efficiency of space usage as evidenced by the location patterns of laptop users. Yet making visualizations of the data available to the public in real time opens up opportunities for more applications that are directly relevant to users of the space.

THE MIT CAMPUS

Our test environment—the MIT campus—can be regarded as a miniature version of an urban neighbourhood. 10,320 students and 9,414 total employees attend the campus, which consists of more than 190 buildings covering a considerable portion of the city of Cambridge, MA. In the year 2000, when laptops were still expensive and wireless Internet new, MIT decided to undertake a vast operation of building a campus-wide wireless network. Since October 2005, this 168 acre campus has over 3,000 active wireless access points providing full coverage of WiFi in all academic and residential buildings. Besides providing a valuable experiment for examining the spatial patterns of IEEE 802.11 WiFi networks, the analysis of such a large wireless network has also offered us helpful insight for studying other types of communication systems, such as mobile phone networks².

The MIT wireless network infrastructure currently uses the IEEE 802.11 protocol exclusively. All access points run by IS&T share the same 'MIT' network name, which permits wireless cards on people's devices to roam seamlessly from one access point to another. The IS&T network division is currently using three different types of wireless access points in the campus-wide wireless network: Avaya Ap-3, Proxim AP3000 and Enterasys AP-3000, with a signal radius from 130 to 350 feet indoors. This allows each access point to serve one or part of a room, as well as neighbouring rooms. The relative positions of the analyzed antennae on campus and illustrates the 'ideal signal availability' in the given set of access points without taking into account physical barriers, such as walls and floor plates, which in reality decrease signal propagation.

In the data that has been made available to us so far, we have observed wireless traffic in up to 2659 unique access points in 134 buildings on MIT's Cambridge campus. Data about some access points are not available to us, as they belong to

Figure 1. Schematic map of the MIT campus

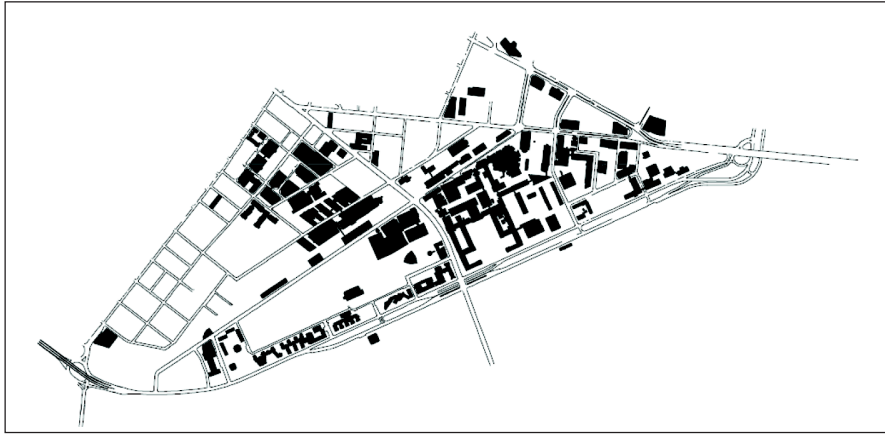


Figure 2. A subset of access points at their locations on the MIT campus

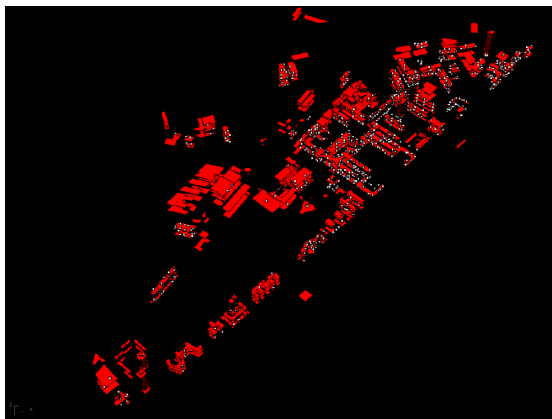
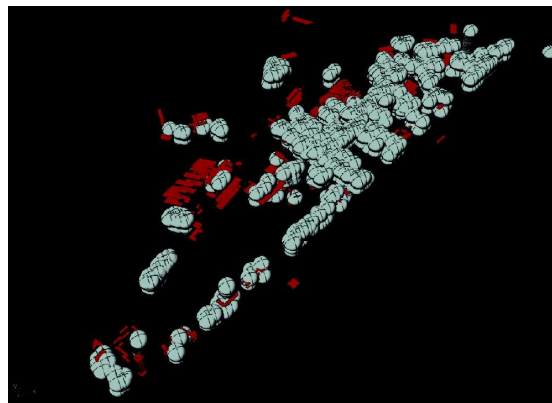


Figure 3. The theoretical availability of the MIT wireless on campus



networks operated privately by individual departments. Others we are not able to map, because the GIS data we have about the campus does not yet include some recently constructed buildings. We hope to be able to update that information soon.

There are also other wireless networks on campus maintained independently within labs, departments, and schools through which one is able to connect to the MIT wireless network (MITnet); however, IS&T does not provide support to the MIT community for these networks (for more information on the specifications of MITnet,

see MIT IS&T, 2007). Two large independent networks whose data we still lack belong to the MIT Media Laboratory and the Computer Science and Artificial Intelligence Laboratory (CSAIL). We plan to obtain their data in the near future and include the two buildings in the overall maps.

While full WiFi coverage is an amenity of many university campuses in the U.S., Dartmouth College being exemplary (see for instance Kotz & Essien, 2005), the number of access points at MIT is manifold greater. Also, a large majority of MIT students, especially in the graduate

community, own laptop computers with WiFi capability, allowing them to freely connect to the wireless network, and the ownership rate has been increasing every semester. According to a study by Dal Fiore, Goldman, and Hwang in 2006, 73% of students bring their laptops either every day or some days of the week to campus. As a result, we have begun to empirically notice changes in the ways that people use the campus facilities for living and working. The intensive evening hours at multiple libraries and the infamous ‘Athena clusters’ — computing labs consisting of networked terminals that any MIT community member may log in — are giving way to heavy wireless traffic at the student dormitories. Similarly, many laboratories, which until a couple of years ago were bustling with people, now have students scattered in nearby cafeterias, collaborative study rooms and lounge-spaces equipped with WiFi.

As part of the iSPOTS project, we created a digital infrastructure for quantifying such changes. However, as data only visualizes wireless activity patterns, there is a lack of understanding about how non-laptop users exploit the campus. At this point it is difficult and perhaps too early to draw clear conclusions about the impact of WiFi on people’s spatial preferences, but work by Dal Fiore, Goldman, and Hwang is beginning to shed some light on the topic.

THE DATA

The spatial analysis of WiFi on campus required data from two sources. The first, obtained from the MIT Department of Facilities, was a geospatial database of all buildings, rooms, and their respective uses as of fall 2005 (buildings and rooms under construction, such as the new student lounge in 10-108 and Building 46, the new Brain and Cognitive Sciences building, are not included in our database). Our second source was MIT IS&T, from which we still keep receiving two constant streams of data. These are data on

Table 1. Schematic for streaming data

Users	Transfers
Access point identifier	Access point identifier
Number of users	Number of bytes transferred
Unix timestamp	Unix timestamp

the number of users per access point, and bytes transferred per access point. Both are measured as totals in 15-minute intervals. A schematic of the streaming data is provided in Table 1.

The overall architecture of the system is shown in Figure 4 Each access point of MITnet is georeferenced using coordinates of the centroid of its containing or nearest room. IS&T runs a program that records the number of times a connection is made to the Internet through one of the monitored access points. Each record is refreshed every 15 minutes. These records are transmitted to a MySQL database on the SENSEable City Laboratory server. Users are allowed to view this data through an interactive widget that displays the number of users over time in a chosen space in the past seven days. The chosen space may be the entire campus, a section of campus (e.g. East Campus, West Campus), a building, floor of a building, or a room.

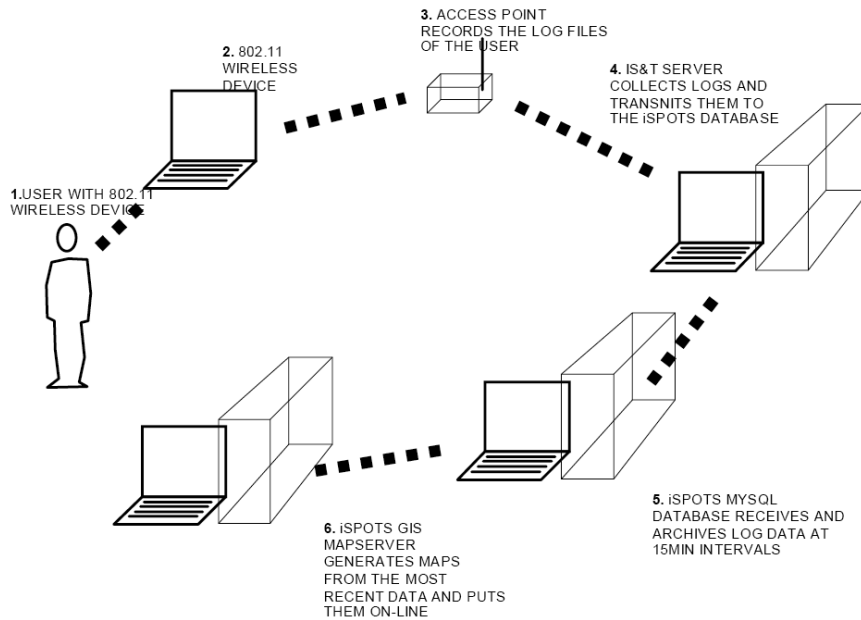
In all public displays of data, the SENSEable City Laboratory follows general guidelines about users’ privacy, under which all statistics we present are in aggregate form and only concern network activity. In other words, no data on individual users’ locations³ is obtained by iSPOTS.

DATA PROCESSING

Real-time maps of WiFi usage

As a holistic means of visualizing the spatio-temporal patterns of WiFi usage on campus, we used an ArcGIS script to generate maps of the campus showing the total number of users for

Figure 4. iSPOTS real time data transfer system



each 15-minute time interval. We further used Macromedia Flash to animate the maps of the latest 24 hours. A sequential visualization of the maps allows users to view how the centres of activity shift between various parts of the campus at different hours of the day. For instance, one can clearly see how the Main Campus (the section of campus housing most of the classrooms) is highly populated during work hours between 10AM and 5PM, while the buildings on West Campus, where most dormitories are located, absorb most of the activity during late evening hours.

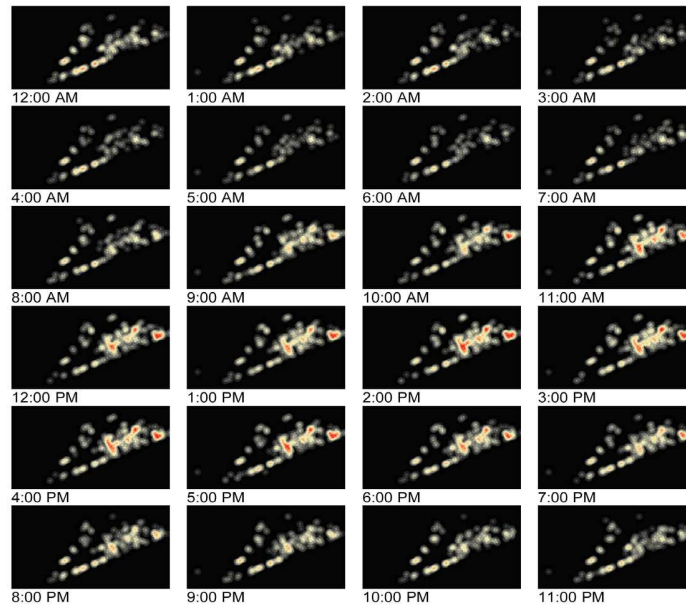
Figure 5 shows an example of campus WiFi usage over a period of 24 hours. The original data from access points is in attributed point format. In order to create two dimensional maps, the punctual data was interpolated using standard GIS functions. The activity of WiFi users on campus, as indicated in the maps, is fairly typical of students who attend classes or work on a weekday schedule slightly later than nine-to-five. The growing spots in the centre and east campus

between 8:00 AM and 10:00 AM show the increase of users logging on WiFi in academic buildings during the start of the work day. Similarly, usage in academic buildings decreases between 7:00 PM and 9:00 PM. The hours between 12:00 AM and 8:00 AM are relatively quiet, though the row of residences on west campus shows users logged on quite consistently.

TIME GRAPHS OF WIFI USAGE

While the maps described above give viewers a holistic sense of user activity on campus, a more accurate picture is revealed with graphs of WiFi use over time for specific spaces. By mapping the number of WiFi users on the Y axis and a time period on the X axis, a unique signature graph is constructed for each access point's activity distribution over a chosen time period. The selection of spaces available to the user included the whole campus, any section of campus (e.g. east

Figure 5. *iSPOTS* maps over 24 hours on Tuesday, December 6, 2005. Brighter areas indicate a larger number of users, while black areas indicate no users connected to MITnet via wireless



campus, west campus), any building on campus, any floor of a building, and any room with a WiFi access point. The default interface creates graphs of WiFi use over the past week, whereas users can also set custom query periods on a separate statistics web page.

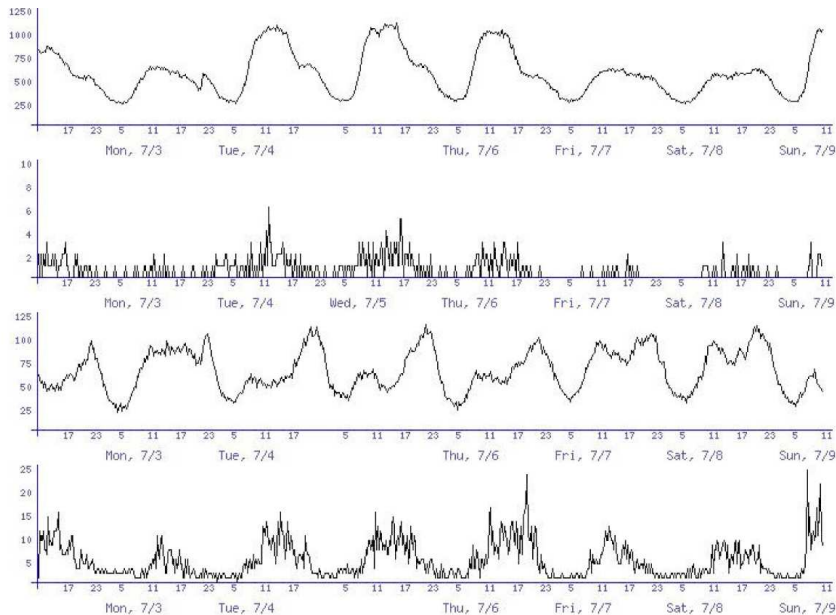
Separating academic, residential, and service facilities over a one-week period shows a fairly predictable pattern of WiFi activity on campus, consistent with the maps above. A one-week graph of WiFi use over the whole campus includes daily peaks typically around 11:00 AM on weekdays, followed by secondary peaks around 8:00 PM. Weekends seem to peak at the same times but with much lower intensity. The first peak is indicative of the high rate of connections made in the morning in academic buildings; a typical academic space witnesses WiFi usage centred around an 11:00 AM peak. The second peak corresponds to the high rate of connections in residences in the evening. Figure 6 shows example graphs of the whole campus, an academic space, a residential space, and a service space.

The double-peaked pattern of WiFi usage we observe over each day appears to be quite common in usage patterns of wireless devices in more general settings. Time graphs of wireless PDA usage on the University California San Diego campus (McNett & Voelker 2003), and bluetooth signals at a city center pub in London (O’Neill et al. 2006) also show a high morning peaks and low afternoon peaks, although the San Diego peaks are a few hours later, possibly because all their subjects are students.

DISCUSSION AND FUTURE WORK

The *iSPOTS* data mapped above has a precise meaning: it shows the amount of wireless devices connected to the network access points at different locations on the MIT campus in real time. During some of the discussions so far, we have made an implicit assumption that WiFi usage information could be used as a proxy for activity and people.

Figure 6. WiFi usage graphs from top: all of campus, fifth floor of Building 9 (Department of Urban Studies and Planning offices), Sidney-Pacific Residence (largest residence on campus), Student Centre



While this assumption probably holds in general terms, a number of biases, both geographical and social, need to be mentioned. Like most behavioural studies, WiFi usage is not likely to exhibit an accurate and periodically repetitive picture of an individual's spatial presence. Both the data and its sampling are too crude for this. In that regard, the spatial analysis of network traffic clearly departs from the more traditional, highly qualitative and in depth studies of social science. However, despite its poorer individual concern, the quantitative network activity based approach allows a far greater sample size and spatial distribution to be analyzed. In addition, once a system is set up, data can be collected over extensive periods of time with virtually no effort involved. A study of its biases and probabilistic representation bounds through data mining, surveys and observations is part of our future work.

One way in which WiFi usage is a biased measurement of actual user activity is clearly, the bias toward spaces where laptop owners are

more likely to be present, and where people with laptops are more likely to connect to the network with their laptops. Classes that restrict laptop usage and paper-based exams are just a few examples of situations where our system would not detect the presence of many people at work.

A second source of bias in the interpretation of the data could be the uneven distribution of laptop ownership: while we are quickly moving towards uniform and saturated ownership, graduate students are currently the segment in the MIT community with the highest proportion of laptop ownership. In addition, laptop usage is likely to vary among different departments, employment types as well as temporal habits. In general, as of spring 2006, IS&T registered an average of 5,373 unique WiFi users per day, about a quarter of approximately 20,000 MITnet users (MIT, 2007).

Third, we realize that laptops are often left connected to wireless Internet when not in use and the iSPOTS system directly measures wire-

less devices and not people. If this information is superimposed onto the data transfer at each access point, it is possible to distinguish between the amount of active and inactive users. However, some biases could still occur (e.g., people may download files when their computer is idle or the machine may be automatically downloading/up-loading program updates). It is possible that such activities occur randomly across all computers, and the aggregate quality of the data is thus not significantly hampered, but graveness of the issue remains to be verified. Recent cluster analysis of the aggregate data has shown that the observed WiFi usage patterns in different types of rooms can quite accurately distinguish the academic, residential and service spaces on campus.

An interesting question that our data can address is: given the increased mobility of users, are traditional land use/space use categories still useful ways to classify space? Or do the overlapping uses such as cafes as workspaces and residences as workspaces imply that we should rethink space classification? Jull and Ratti's (forthcoming) analysis provides some evidence that building signatures still correspond to basic space use designations, though we may still expect this to change.

Finally, we recognize that the university campus differs systematically from general urban environments in ways that would be reflected in WiFi usage patterns. For example, the characteristic late-night usage in residence halls is probably a trait endemic to students, who comprise half the university population. More studies in diverse settings would contribute to our knowledge of behavior in urban environments, but campuses may provide the most comprehensive urban sub-setting to the extent that they provide many regular urban functions, including facilities for work, residence, recreation, and other support services.

While we continue working to address the accuracy issues highlighted above, the iSPOTS data can already be used in a qualitative way for

campus planning purposes. The data reveals the dominant trends in people's mobility and may be used to substantiate with numerical evidence observations that have been simply anecdotal so far. The Campus Planning Committee of MIT, for instance, could take notice of the emerging spatial changes of life and work environments, and redirect their efforts to support the new trends. A good example is the recently completed 'Steam Café' on the fourth floor of the architecture building, which underwent a complete remodelling during January 2005 (<http://steamcafe.mit.edu>). The design and execution was left in the hands of architecture students, who not only used the opportunity to redesign the café, but also re-conceptualize the café's image and menu. Before its conversion, the area that is now Steam Café was used by few and only for a limited time each day—the lunch break. Now, thanks to the overlapping of different activities, the presence of WiFi, and a new concept in design (not to mention better food), it is active around the clock. Sales have increased three-fold and the Campus Planning Committee is beginning to recognize that a more efficient environment could emerge by extending similar concepts to the whole campus.

It is also possible to imagine future scenarios, based on the iSPOTS system:

Scenario 1. When the MIT Campus Planning Committee engages in negotiations with a new evening snack cafeteria to open on campus, they can use the iSPOTS archive to aid their decision in site selection. With a few simple queries, they may find, for example, residence areas where WiFi usage shows large numbers of users during afternoon and evening hours. They might even find that the best opening hours for the cafeteria are not standard 9-to-5 working hours, but rather, when most wireless usage occurs in the vicinity.

Scenario 2. A more sobering yet still realistic application is emergency situations. For example, if a security alert, such as a fire alarm or a toxic gas leak occurs in a large building, then security officers could easily check the current status of

WiFi usage in that building and make an intelligent guess about how many people might be inside the building. The predictive capacity of the system depends on calibrating the models with empirically observed usage patterns. Even though not everyone uses WiFi and as most people only use it for a limited period during the day, corrections could be applied to the data by using statistics that have been observed over longer periods of time. For instance, with an accurate estimate of the percentage of laptop users in a building and among those, the percentage of them that are WiFi connected, one may calculate the total predicted number of people in the building with fair probability (cf. Nakanishi, Ishida, & Koizumi in this volume).

Scenario 3. Most certainly, the real-time on-line database could become a useful and fun information tool for MIT students on a daily basis. For instance, an architecture student, who is working at home, might be wondering if it would be better to work in his/her studio at school, because other friends might be working there too. In this case he/she could go on-line to the iSPOTS map and run a query for the given studio space and see how many people are currently using wireless internet in that space. If the network turns out to be busy, then he/she might want to move and join the others. A prototype application “StudioBRIDGE” for the department of Architecture was shown to be useful for this purpose: users did find it useful to check for the presence (without identity) of other users in studios before entering (Yee and Park 2005). For a more general application, it would be most useful to add contextual information to the data, describing how the current presence of users in a certain space compares to the historical average presence of users in the same space and similar time of the day. Furthermore, based on the recent data from the same space, it would be useful to indicate whether the amount of users is currently stable, growing or diminishing.

There are many other examples of possible uses for the real-time analysis capacities of the iSPOTS

project. The availability of real time views of the campus activity can allow the creation of feedback mechanisms, which prompt reactions similar to those observed in real time control systems (for a general introduction to control systems see Shinner, 1998; for an exploratory discussion of what that might mean in the urban context see Mitchell, 2005, and Calabrese, Kloeckl and Ratti, 2007). A similar implementation might in the near future apply to neighbourhoods or even cities at large, where urban processes could be observed in real-time from the broadest flux in the city to the highly specific queries about single buildings. As urban GIS data are expanding world-wide, greater opportunities are created for urban analysis. In addition, GIS data exchange over the Internet also enables information to be shared from multiple other databases in the city or around the world. In short, the ever-increasing amount of urban data that are recorded every day with painstaking precision can find many uses in an on-line environment, which enables either all or selected users to find vast amounts of accurate real-time information about the city around them.

The implications of a real-time mapping exercise include not only a new tool for mapping, but also a changing perception of the campus or city as a whole (Ratti and Berry, 2007). We acknowledge that the goals and representations of such mapping are clearly different from traditional urban mapping, and we do not want to contest the value of such maps. Rather, we hope to enrich the palette of urban mapping by introducing a new tool, which can help us visualize the city as a set of processes and broaden our perspective on the complex interrelationships of its elements. If the image of a map changes from static to dynamic and acquires different layers of real-time information, then the map is no longer a fixed reference, representing the durable objects and spaces of the city. A real-time map becomes as lively as the urban environment it represents, and is literally shaped by the users of the environment. In a real-time map, not only urban elements, but also processes are spatially

represented. A public on-line distribution of the map allows large numbers of people to monitor the urban flux simultaneously, thus raising the public awareness of the dynamism of the contemporary city through simple cartographic evidence.

Finally, visualizing aggregate people's movement through secondary sources such as WiFi, is of course not the same as understanding the movements and the causes behind them. Spatial analysis of wireless network traffic merely creates an opportunity for urban scholars to perceive the interactions between people and the built environment. As two dimensional mappings of thousands of users in actual spaces, the iSPOTS maps collapse a great deal of complex information into single images. We acknowledge the challenges and dangers of omitting valuable qualitative data from such representations and focusing perhaps too much on a single chosen variable: the spatial presence of people, which can blind one from a more nuanced understanding of spatial occupancy. The untangling of the complex causal and correlational relationships between physical spaces and their human use is still waiting for its thorough scholarly study, and we look forward to participating in such future work.

CONCLUSION

This chapter reviews ongoing research on the iSPOTS project at the MIT campus in Cambridge, MA. The aim of the project is to analyze usage of the wireless Internet network in order to describe occupancy patterns and movements of its users. Interim results seem to suggest that this type of analysis is powerful and could have many applications—whose relevance could extend to entire cities in future years when they become wireless.

iSPOTS takes real-time data about usage on WiFi access points as a measure of how people use space on the MIT campus. We created interfaces to retrieve data in the form of colour-coded maps

and time graphs, for users who may be interested in analyzing the use of specific spaces. We found that data on individual user locations can be useful to users themselves through a peer-to-peer social networking and location-sharing applet. In the next few years, as wireless computing continues to expand into wider urban areas and programs that depend on ubiquitous wireless computing, our system may inform urban planners and administrators of these environments and programs of likely user responses to spatial conditions.

Regarding the MIT campus, we hope that iSPOTS data will soon shed light on a number of changes that are happening due to pervasive wireless accessibility. In particular, we would like to validate or disprove a number of hypotheses. For instance: are we really witnessing a switch towards increasing mobility in individual working patterns? Is it true that traditional classifications of space do not hold anymore, as people are changing their working patterns due to the introduction of wireless communication? And finally, one of the most important questions for architects and planners: if you can be at work anywhere, where would you like to be? What are the architectural qualities of spaces that people vote for with their feet?

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KEY TERMS

Real-Time Map: instantaneous and dynamic visualization of an environment.

Wireless Mapping: graphic representation of digital activities in a wireless communication network.

GIS: Geographic Information Systems

Urban Dynamics: A description of the changing movements of people, objects and information in a city.

WiFi Hotspot: An area around an Internet access point where people can connect to the Internet through their wireless communication devices.

Spatial Occupancy Study: an analysis describing how people use certain built spaces over time

MIT: Massachusetts Institute of Technology

ENDNOTES

- ¹ Some of the pilot cities like Chicago have, however, run into financial and technical difficulty in setting up city-wide free WiFi, which has set the trend in question.
- ² For instance the Real-Time-Rome project: <http://senseable.mit.edu/realtimerome/>
- ³ The voluntary sharing of individual information, on a peer-to-peer opt-in platform is the focus of our subsequent project called iFIND (<http://ifind.mit.edu>).