Automation in Construction 89 (2018) 275–291

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

# Landscape of connectivity. Measuring and representing fluctuations in wireless network traffic in space

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ARTICLE INFO

*Keywords:*
Wireless connectivity
Built environment
Indoor positioning
Infrastructure design
Wireless network planning
Designing for connectivity

ABSTRACT

Measuring and understanding the propagation of wireless network signals in buildings is an important task for the planning of both architecture and wireless networks. This article documents an approach to understanding the wireless network traffic load in a location-specific manner, based on the users. The traffic counting system enables relating of traffic load (both cellular and Wi-Fi) to a position in space, using *Connect or Not* smartphone application. Positioning tracking is based on two technologies: Wi-Fi fingerprints, created using existing networking infrastructure and Bluetooth beacons installed at testing locations. The positioning system is able to track movement through space to a satisfactory level.

The system was tested in the context of interactive installations as well as long-term observations of user behaviour in space. These experiments facilitate the conceptualization of a communication landscape, highlighting the activity of people and devices in the network layer. The system can, thus, be useful for post-occupancy evaluations. Moreover, it enables a profound understanding of signal propagation and use patterns in space. We argue that the compound measurement of these two phenomena, which are rarely related, forms a productive base for understanding the relevance of built architecture for the design of wireless infrastructures, and vice versa.

## 1. Introduction

Wireless communication has an ambiguous relationship to architectural design. On the one hand, architects do not design space for wireless connectivity: network planning and installation are executed by network engineers following the building completion. On the other hand, we are increasingly aware of the impact connectedness – or disconnectedness – has on the use and functioning of spaces. Kitchin and Dodge identified the airport check-in area as a space where functioning connectivity is more important for the use of space than its physical design [15]. Wireless communication technologies raise the question of connectivity to the environmental level, where a range of devices rely on a consistent network infrastructure. Networked services such as wireless sensor networks and the various Internet of Things technologies: smart appliances, robot-assistants, self-diving cars expect seamless connectivity across space.

Researchers have approached the expansion of wireless communication infrastructures from different perspectives. In ethnographic studies relating the use of space and connectivity in everyday situations, Forlano and Hampton explored the use of free Wi-Fi networks in public space [9,10]. Both Forlano's and Hampton's investigations found a strong correlation between the availability of networks and people's experience of space in terms of preference (where to go) and qualities (comfortable and connected or not).

Researchers in urban planning and architecture used computational spatial analysis to study the way networks are consumed by people in space [12,28]. The findings from these studies are more reserved, but they recognize a correlation between the dynamics in people's use of space and networks.

Coinciding with the massive adoption of wireless communication technologies, human-computer interaction researchers proposed to consider the presence of wireless networks more tangibly. Chalmers articulated these efforts as the *seamful* design approach [6] and several notable projects, such as the Seamful game came out of this research [7]. Similar approach was taken by his Swedish colleagues who [26] explored intentional design of interaction with "seams" in connectivity, rendering the availability of networks in space directly perceivable and meaningful. Our work with tangible experience of wireless networks fluctuations has been influenced by efforts to constitute a *seamful design* approach to the interaction with network technologies.

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https://doi.org/10.1016/j.autcon.2018.02.010
Received 2 December 2016; Received in revised form 27 December 2017; Accepted 2 February 2018

These efforts are motivated mainly by the perceived lack of debate outside of engineering circles on the way this technology is designed. Incidentally, we recognize the difficulty to integrate planning of wireless networks with the planning of buildings and cities. This difficulty is slowly becoming relevant in communication engineering research. A research team based at University of Sheffield and Czech Technical University explored signal propagation relative to materials buildings are made of [35], as well as the potential of frequency selective materials and collaborative autonomous wireless infrastructures to manage connectivity demands across different parts of the building [33,34]. Communication industry insights also point at the importance of designing network infrastructure simultaneously to the building design [25]. Our research is an attempt to conceive a generic system that could enable fast and architecturally-relevant analysis of network use in space.

Wireless communication infrastructure is still rarely discussed from the point of view of the space they occupy or the experience of connectivity they afford. In this paper, we propose a way to quantify and analyse the distribution of wireless connectivity and the way it is used by people and machines.

Quantification is performed by a specially devised measurement system – a smartphone application and a remote server. The system gathers data on traffic use from individual devices, coupled with their location. It centralises this data on a remote server for its use in data analysis as well as in interactive installations. The design of the system is based on the assumption that, in a situation where people are present, the majority of network traffic is generated on wireless-enabled devices. We developed a smartphone application to be able to access this data on devices. The application also provides indoor positioning through a combination of Bluetooth beacons and Wi-Fi fingerprints. We tested this system in different settings and improved it during this process.

## 2. Materials and methods

Relating wireless network traffic activity to a position in space would not be possible without the ability to measure that traffic in some way. Options here were the following: universal traffic sniffers or smartphones. We decided on the latter because of their ubiquity and because sniffers are largely viewed as intrusive and illegal in Europe.[1] Additionally, smartphones now represent a large part of the global internet traffic and their intrinsic mobility offered interesting further developments [32]. We have considered monitoring network traffic (using Aircrack-ng software to count packets on all Wi-Fi networks). We also considered spectrum scanning using software defined radio tools (GNU radio and a DVB-T dongle based on the Realtek RTL2832U). For the purpose of this research we decided to focus on counting traffic where it is created – at the device side. Assuming that the most significant amount of traffic is generated on wireless-enabled devices, and that this traffic load also accounts for machine-to-machine communication with the technology embedded in space, we opted for a per-device measurement strategy.

We developed the *Connect Or Not*[2] smartphone application which quantifies the use of networks (both cellular and Wi-Fi) by counting data the device has transferred over different communication channels. With each measurement, the application attempts to locate the device in a marked-up space using Bluetooth beacons and Wi-Fi fingerprints. The application thus gathers usually unrelated quantities: data consumption by smartphones and their location.

The indoor localization technique is based on an approach conceptualized by Bahl and Padmanabhan [2] and Chen and Kobayashi [8]. Their idea was to investigate statistical learning theory for location fingerprinting, connecting measurements of received signal strength (RSSI) to a position in space. We used the Support Vector Machine (SVM) classification technique to improve precision of the system, trained on a manually performed set of measurements.

Position tracking in the *Connect or Not* application is based on two technologies that work together, but are not mutually dependent. One is a set of Bluetooth light energy beacons produced by Estimote, which allow for low-resolution positioning within a previously tagged space. The other is a system based on Wi-Fi fingerprints, which uses Redpin indoor positioning system developed by Bolliger and colleagues [3] as a base for triangulating position, and reaches a precision of about 1.5 m at best, and up to 5 m.

Wi-Fi fingerprints are impressions or traces of radio signal broadcast by Wi-Fi access points. A fingerprint is made of a measured intensity of the received signal strength (RSSI) at particular points in space, together with parameters such as the MAC address of the AP, and a timestamp. By collecting “fingerprints” at different positions in space, the system is able to estimate position based on similarity of the current measurement to an existing one in its database. Wi-Fi fingerprints are particularly interesting because they rely on an infrastructure that is already available in space.

*Connect or Not* application was developed for the Android operating system, which enabled us to have a relatively short prototyping phase and release the application in the PlayStore quickly. The focus on one type of smartphone resulted from the aim to build a proof-of-concept rather than provide a universal service. The later can easily be accomplished in our future work.

In its first version, the application was counting network activity and broadcasting it over OSC (Open Sound Control) protocol. We introduced a position tracking system later, together with centralisation of data on a remote server. The development process centred around structural and design choices which would demand minimal engagement from the user while providing data on traffic and movement of the device. Throughout the work, public demonstrations offered the possibility to test and improve the application. A significant part of the development was guided by findings from these demonstrations. We describe these steps chronologically: gathering data, making it accessible and adding localization.

### 2.1. Gathering data on traffic load

Wireless signals spread within buildings in a way that is modified from the ideal signal propagation by the actual permeability of construction material. To study the relationship between built structures and seamless infrastructures, we put our focus on the distribution of wireless signals in space and their load (the amount of traffic). We evaluated signal traffic load per device, through the use of a traffic counter Android application that tracked calls duration, the number of text messages and bytes of Internet traffic. The application is available in Google Play Store[3] since January 2014.

The first step towards implementing the system was to efficiently evaluate network traffic. The main existing application that caught our attention for this step is called *NetCounter*.[4] It was written by Cyril Jaquier and released in the Google Play Store in 2010. Its goal was to facilitate tracking of data usage for its users (for example to avoid going over a monthly data cap). It is open-source, well written, and published under the GPLv3[5] license, all of which were key to building an application from a solid base, reusing some of the original *NetCounter* code.

The first difference from the *NetCounter* application is that we wanted to gather information from multiple phones, therefore we

[1] Directive 2002/58/EC grants European citizens a right to privacy of communications and discourages packet sniffing techniques required to gather information on network traffic http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0058:en:HTML.

[2] http://connectornot.emperors.kucjica.org.

[3] https://play.google.com/store/apps/details?id=net.lmag.connectornot.

[4] https://play.google.com/store/apps/details?id=net.jaqpot.netcounter&hl=en.

[5] https://www.gnu.org/licenses/quick-guide-gplv3.html.