ARTICLE IN PRESS

Pervasive and Mobile Computing ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Pervasive and Mobile Computing

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

Making infrastructure visible for nomadic work

Gloria Mark*, Norman Makoto Su

Department of Informatics, University of California, Irvine, Irvine, CA 92697-3440, United States

ARTICLE INFO

Article history:
Received 23 March 2009
Received in revised form 8 September 2009
Accepted 29 December 2009
Available online xxxx

Keywords:
Nomadic work
Mobile work
Ubiquitous computing
Infrastructure
Ethnography

ABSTRACT

In this study we revisit Weiser's (1991) [5] vision of seamlessly integrated computing. We focus on nomadic workers who rely extensively on mobile technologies to conduct work. Using Star and Ruhleder's (1996) [10] properties of infrastructure, we discuss how nonroutine users of infrastructure face particular challenges. We conducted an ethnographic investigation of nomadic workers in a large distributed organization. We examined strategies that they use to assemble their mobile office, to seek resources, and to synchronize with others across time zones. We discuss how their strategies are challenged by their lack of local knowledge of infrastructure. Our results suggest that until the field of pervasive computing can attain Weiser's vision, the very users of ubiquitous computing need infrastructure to be visible. We discuss the implications for a design to support nomadic work.

1. Introduction

Nomadic work is becoming more prevalent in organizations. The term nomadic worker is derived from the term nomad, a member of a community who travels from place to place with a purposeful goal. Similarly, nomadic workers (**NW**s) travel with the goal of conducting work. Paul Erdös, the Hungarian mathematician, is perhaps the prototypical academic NW who traveled from university to university to collaborate with other mathematicians. In nomadic work employees travel most of their work time to meet with distributed team members, customers, vendors, or other colleagues who may be inside or even outside of the organization. One large distributed Fortune 500 company recently conducted an independent survey[1] which identified approximately 20% of its workforce as NWs.

We expect that due to technological advances and economic savings for organizations, nomadic work will continue to increase. Trends such as cloud computing enable people to keep their documents online, accessible from anywhere, as opposed to working on a single laptop. The continued development of mobile device infrastructures which enable BlackBerry, laptop and cell phone use is moving towards ubiquitous connectivity [1]. There are several social and economic advantages of nomadic work for both workers and employers. The flexible time enables workers to have a better work-life balance. Traveling to meet with customers for face-to-face interactions may lead to higher customer satisfaction. The maintenance cost of workspace shifts from the company to the employee. Finally, some employers feel that freedom from the potentially demoralizing containment of cubicles leads to increased worker productivity and a better work/life balance [2, 41]. On the other hand, fears have been articulated that nomadic work will lead to higher levels of stress, decreased work productivity and quality, security issues, and high management costs [3].

Nomadic workers travel far more than "flexiworkers" [4] and "road warriors" [2] in terms of their length of time and geographical diversity in travel. We consider nomadic work to have three criteria. First, NWs travel most of their work time.

* Corresponding author.
E-mail addresses: gmark@ics.uci.edu (G. Mark), normsu@ics.uci.edu (N.M. Su).

[1] Survey results were conveyed through personal communication.

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doi:10.1016/j.pmcj.2009.12.004

Second, most NWs are not associated strongly with any single home office, nor bound to any particular company office. They work wherever they happen to be, which may be a company site, at home, at a customer site, in hotel rooms, coffee shops, rental cars, airports, and so on. Finally, NWs are responsible for carrying, managing and reconfiguring their own work resources, whereas traditional office workers can rely on a relatively stable set of resources that they use in their home, office, or other routine use of space. Indeed, the organization in which our fieldwork was conducted has recognized that NWs are a different class of worker, separate from traditional telecommuters. While we do not claim our definition of NWs to be definitive, we believe our description to be accurate for the self-identified NWs from our informant pool. To our knowledge, nomadic workers have not been sufficiently distinguished in other literature as a special case of mobile workers.

We are interested in how NWs manage and use resources as they navigate through different environments. We approach this question from a sociotechnical perspective as the challenge of finding and using technical resources is situated in a larger social and organizational context. The NW must constantly seek and rely on both human and technical resources to satisfy their needs, which are interdependent with social structures such as organizational policies. Therefore, we argue that to deeply understand how to design support for nomadic work practices, it is necessary to understand the nomadic life *in situ* in the organization. To our knowledge, though there have been studies addressing social aspects of mobility (to be discussed shortly), there has been a lack of attention as to how organizational design impacts nomadic work.

2. Infrastructure for ubiquitous computing: The challenge for invisibility

As Mark Weiser so aptly pointed out almost two decades ago, "*The most profound technologies are those that disappear*" [5]. Weiser had envisioned a world where computers that activate the world disappear into the background. In such an ideal landscape, we would enter our homes, the temperature would regulate to our preference and water would be drawn for our bath at our preferred time. Weiser's dream of homes and office buildings that can recognize a person's identity and adapt to their preferences is suited to routine behaviors. Our interest is in the work practice of extremely mobile, or nomadic workers, whose behaviors in many environments foreign to them are in fact anything but routine.

Though nomadic workers have developed particular strategies for "survival" as they navigate through different environments, we focus on one particular challenge: connecting to a ubiquitous computing network. Weiser's vision of a seamless connection is unfortunately still a dream at this point in time. Indeed, recent articles have begun to question the primacy of invisibility in research on ubiquitous computing (e.g., [6]).

We are interested in the role of infrastructure in supporting a nomadic worklife. There has been some attention given to how technical infrastructures affect people's technology use and interaction [7–10]. Using a particular infrastructure on a regular basis enables people to learn its intricacies. For example, people learn where the local hotspots are or how to stop an idiosyncratic water faucet from leaking. This local knowledge of infrastructure gives an advantage to local users. Local knowledge is often tacit [11] and thus personal, context-specific, gained from experience, and not easily communicated. Nomadic workers, who are transient visitors at a site, lack such local knowledge and thus lack this advantage of understanding the local infrastructure.

As Star and Ruhleder [10] describe, infrastructure is fundamentally relational. To a handicapped person, ramps and banisters are critical aspects of infrastructure; to those not handicapped, these elements recede into the background. In the case of nomadic and local workers, infrastructure is very relational. Elements of the infrastructure that are taken for granted by local workers may be unknown to nomads who visit their site and must discover them. A common example is achieving Internet connectivity. To a local person, wireless connectivity has already been set up at their workplace and is likely then automatic whenever they enter their workplace. A NW in turn must discover where the wireless networks are and may need computer support to set it up. In contrast, those unfamiliar with air travel and airport layouts may not know prime locations of electrical sockets for powering laptops, knowledge that NWs should have.

Some infrastructure knowledge is fairly universal across geographical locations. Stop signs, for example, retain the same red color and similar shape in many countries in the world though the languages are different. Electrical outlets, though varying in the dimensions of plughole size and number, still are recognizable around the world due to common characteristics such as holes, placement in the lower part of walls, etc. With the compatible plug (which does require specific infrastructure knowledge) then it is straightforward to obtain power.

In this paper we use what Bowker [8] proposes as an "infrastructural inversion" as a methodological device. This figure/ground reversal places infrastructure in the foreground and reveals its relational nature. By focusing a lens on elements of the infrastructure that are normally in the background of work practice it can reveal how infrastructure affects nomadic worklife. In a broader sense, it can inform us of the role of infrastructure in pervasive computing design.

Star and Ruhleder [10] consider that technical infrastructure is interwoven with human infrastructure (the pattern of social arrangements of people) and they identify a set of properties that define this relationship. People who live and work at a location use infrastructure routinely, and Star and Ruhleder's properties, which are targeted towards routine use, may serve to define characteristics of infrastructure for this set of users. For those who are faced with using an infrastructure that is unfamiliar, these properties may take on different meanings. We add to the properties of Star and Ruhleder, listed below, by discussing how these properties would apply to nonroutine use of infrastructure, as with the case of NWs.

Embeddedness. Infrastructure is embedded inside of other structures, social arrangements, and technologies. These coordinated aspects of infrastructure may be implicitly understood with routine use. With nonroutine use, however, people may not be aware of how infrastructure is related to social arrangements.

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Transparency. With routine use, infrastructure is transparent to use. For each task, it does not have to be reassembled. With nonroutine use it must be discovered how it can be used, and sometimes even reinvented.

Reach or scope. With routine use, infrastructure has reach beyond any single event. Wireless connectivity, for example, can be used for laptops or PDAs or printers. With nonroutine use its reach or scope for different devices may not be readily apparent.

Learned as part of membership. People who are members of a community of practice (CoP) [12] learn how infrastructure relates to the practices of that CoP. People outside the CoP are unfamiliar with how the community uses infrastructure.

Links with conventions of practice. Infrastructure is affected by the conventions of a particular culture which may be associated with country or region. In Germany, the "Z" and "Y" keys are in different positions on the QWERTY keyboard in contrast to North America to reflect different patterns of letter use in the German language. A North American traveling to Germany must learn to adapt to German keyboards.

Embodiment of standards. Employing standards, infrastructure can plug into other infrastructures and tools. A stranger to the infrastructure may have infrastructures and tools that lack compatibility with a local infrastructure.

Built on an installed base. Infrastructure is built upon an existing base. This legacy base constrains and defines the capabilities of other technologies that connect to that infrastructure. Infrastructure may be shared across organizations and regions; therefore it is not easy to change infrastructure [13]. Nonroutine users of infrastructure may lack the understanding of the extent to which it constrains other technology use.

Becomes visible upon breakdown. People are generally not aware of infrastructure until it breaks down. When the Internet server is down or when the plumbing system fails, then people take notice. Nonroutine users of infrastructure may become highly aware of infrastructure when they cannot get it to work with their own systems. For routine users if it is functioning as they expect it to it thus remains invisible.

3. Related work

A wide range of literature drawing from the ethnomethodological perspective [14] has examined the interplay between technology and mobility in a single site. Studies on the inherent difficulty in trying to replace *paper* with digital artifacts highlight paper's excellent "micromobility"—it's ability for conveying subtle, ephemeral cues quickly with coworkers in a variety of localities [15]. Mobile systems that were developed to replace paper ended up hampering routine work of traveling around remote sites [16]. Other work has shown how mobility is a useful *strategy* in sharing resources such as scanners and in facilitating face-to-face meetings [17]. A study focusing on newer portable scanners found they functioned as personal, and not shared, resources [18]. These studies predate the ubiquitous introduction of wireless networks.

Research in the medical domains has the particularly difficult task of facilitating mobility among the elderly who often have physical and cognitive disabilities [19]. Ubiquitous technologies that support the mobility of the hospital staff has noted that information needed for the patient record was often fragmented, and the records had to be reconstructured through mobility [20]. Bardram [21] examines the problems of login systems for patient record systems and notes a disconnect between a login that is associated with a single computer and the fact that medical work is "nomadic". In an earlier study Bardram and Bossen [22] note that there are four aspects of mobility work in the hospital that are configured and assembled: resources, persons, places and knowledge. While we noted the same concerns for nomadic workers, Bardram's studies focus on mobility within a single site, the hospital. These and earlier studies have focused on employees that have a primarily home base in which local practices have been developed, maintained, and implicitly understood over time by a stable set of actors.

More recent studies investigate the practices of mobile workers on the road. For example, Perry et al. [23] collected data around actual business trips, conducting interviews and observations before and after the trips. The resultant themes dealt with planning for the unpredictable, working in "dead time", usage of remote aware tools and a mobile phone as proxy. Brown & O'Hara's [24] study is an expansion of the former, adding data on "hot-deskers"— office workers without a fixed desk. Brown & O'Hara frame their analysis through "work changing place" (e.g., café transformed to office) and "place changing work" (e.g., office as a site for informal interaction opportunities). The data from these studies are drawn from workers from independent sites as opposed to our study, which focuses on a single organization implementing mobile work policies. However, we will draw on some of Brown & O'Hara's work on 'hot-deskers', as they face similar issues as nomadic workers.

A range of studies have been done on telecommuting. Such studies have revealed that a model of telecommuting based on a strict delineation of work and home are inadequate. Beasley & Lomo-David [25] found that motivations for telecommuting stemmed primarily from flexible working hours and more time with family. Habib & Cornford [26] studied the impact of telecommuting on family life and identified four key elements that are affected when a virtual office is added to the home: new roles for family members, reorganization of time management in both home and work aspects, reorganization of space due to the virtual office and family budget changes. Salazar's [27] study found that boundaries between work and home life were a continuum for telecommuters, unlike traditional office workers. Motivations for working at home included having a quiet environment, comfort and convenience and to be close to the family. Our research certainly plays out some of the issues of the boundaries between home and work life but our focus is on why "home" is a site of work for nomadic workers, and why, for example, some nomads actually have more than one home.

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Technical approaches have targeted building infrastructures appropriate in mobile contexts. Kleinrock [28] notes that compatibility problems between technologies threaten to undermine the creation of convenient and capable nomadic computing devices. Gerla [29] argues that commercial mobile ad hoc network (MANET) technologies need a different set of requirements compared to those of the traditional military/government (who fund much of the MANET research). For example, monetary cost, standards compliance, and Internet connectivity are major issues. Both Gerla's and Kleinrock's issues of incompatible infrastructures will be touched upon on our study. As a solution, Aiello and Dustdar [30] suggest creating a web service-based infrastructure to allow heterogenous home appliances to interconnect.

Research has been done on designing interfaces appropriate for mobile work. For example, in their fieldwork of ecologists, Pascoe et al. [31] highlight two design principles when creating interfaces to be used while moving: minimal attention user interfaces (MAUIs) and context awareness. A MAUI is "about shifting the human-computer interaction to unused channels or senses…in a way that is not so cognitively demanding to distract the user from the task at hand" (p. 425–246). Applying the MAUI principle to a mobile application for recording giraffe observations, ecologists are able to focus their visual senses on the giraffes, while simultaneously using their the tactile feedback of the PDA's buttons to tally data such as giraffe bites.

In addition, there are an increasing number of studies on the pervasiveness of technological infrastructures in domestic life. Woodruff et al.'s [32] study on wireless laptops in the home revealed that people formed favorite places to move laptops to depending on the task at hand (e.g., places for serious work vs. places for comfort). Grinter et al. [33] note that different households have different conceptions of how a wireless network operates and that invisibility and comprehension of the inner workings of such devices can be simultaneously desirable.

Finally, this work builds upon our past work on NWs [34] that drew from the anthropological literature on pastoral nomads to unpack the problems of NWs in an organization. However, in this paper we bring to the forefront and analyze the notion of invisibility in terms of the *infrastructure* of ubiquitous computing. Thus, our analysis and discussion in this paper expands on the importance of infrastructure's relationship to NW behavior and practices.

4. Field site & methods

The methodology we used to understand the role of infrastructure for nomadic workers was ethnographic investigation. Ethnographies assume that through observational fieldwork the researcher can extract a holistic understanding of the phenomena. Through fieldwork it allows the researcher to understand the system as a whole because of the interdependence of the informant, people, the environment, and other social structures. Our ethnographic inquiry draws from two sources: interviews and in situ observations of NWs. All informants are from a large, distributed US headquartered corporation, we call Global Inc,[2] which manufactures computer hardware components.

Our dataset consists of a total of 22 semi-structured in-depth interviews and observation of six NWs over the course of one week at one work site in the US. First, we conducted interviews by telephone, catching the NW wherever he or she was at the time. Some of our informants were at home, hotels, cars, or different worksites during our interviews. During our interviews some NWs were mobile, speaking with us on the phone as they were walking to a meeting, driving a car, or carrying out errands. Some of our informants were in Asia, Europe, or different North American coasts at the time of the interviews. The interview protocol addressed the NWs' different projects on which they were working, sources of stress, working environments, amounts of travel, technology use, interruptions in the workday, and methods of being reached and reaching others. Interviews ranged from 45 min to 1.5 h and were audio recorded and transcribed.

Second, we collected data from NWs who arrived at a particular site of the company located in the US For a one week period, observations were conducted at one of the work sites of Global Inc. to gain a detailed understanding of the problems that NWs face when they work at a nonroutine location. One author traveled to a particular office of Global Inc. and met (arranged by our internal contact) the NWs, explained the study's goals, and then shadowed each employee individually. Shadowing is an intense form of participatory observation where the researcher unobtrusively follows *as closely as possible* the informant during the workday. The researcher observed all the informants' activities and time-stamped each activity to the second so that we could understand how long different operations took. Additionally, the researcher recorded all artifacts used by each informant, the people with who the informant interacted, locations that the informant visited, and all problems encountered. Typically, each NW was shadowed for four hours, either from the beginning of the workday till lunch, or from lunch till the end of the workday. Shadowing has been shown to be an effective method for collecting data amenable to both qualitative and quantitative research [35]. While diary studies may have been feasible, they have a drawback in requiring *a priori* a framework to theorize behavior that is then reflected in the diary form the participants must fill out [36].

It was a challenge to collect data for NWs due to their extreme mobility. While shadowing NWs as they travelled (e.g., in cars, trains and airplanes across continents) would have been ideal, this was prohibitively expensive and intrusive for the NW, as the borders of their personal and work lives are blurred. Thus, our study primarily focuses on how nomadic work is accomplished in the workplace since an ethnographic observation of NWs in transit was not feasible for us as researchers. Certainly, important work in nomadic work is done outside the organization, in hotel rooms, cafes, and airports. However, we believe the triangulation of both interviews (which often revealed practices done outside the workplace environment) and observational data allow us to derive a rich narrative of real nomadic work.

[2] A pseudonym.

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Four informants are "based" in Israel, while the other 18 are "based" in the US. Contacts at Global Inc. recruited nomadic employees to interview with us. Our informants had a range of work roles: directors, market research analysts, a technical assistant, strategists, managers, an IT Planner, a research scientist, a publisher, engineers, and an architect. Nine of the informants are involved with the marketing or business side of Global Inc. Interaction is a large part of all the informants' jobs.

The nomadic life of our informants ranged from some who traveled in bursts to those who traveled most of the time. Extreme NWs traveled extensively and regularly. One NW in our sample averaged 200 days/year on the road for the last 25 years. Two informants each owned two homes in different US states. One NW owned a home in Las Vegas. He described that he chose that location because Las Vegas airport has the most red-eye flights in the US.

We used a grounded theory [37] approach for thematic generation. Interviews and field notes (from shadowing) were transcribed and coded in Atlas.ti, a software for qualitative data analysis. Coding was done on a line-by-line basis using both open and axial coding methodologies. For example, open codes "network" and "IT support" were respectively utilized for lines regarding network connectivity in various settings and contacting support centers for troubleshooting company equipment. These categories were then seen as overall related to each other in terms of NWs seeking "resources" (an axial coding) in nonroutine environments. We stress however, that we constantly went back and forth on our codings – open and axial coding phases were intertwined not strictly sequential) – to refine them.

5. Nomadic workers and infrastructure use

We begin by describing an overview of the nomadic worklife. NWs generally work long hours when they are travelling with little or no "off time". While travelling or working at different locations they are expected to attend meetings with colleagues at their home base during their "regular" work hours, even though NWs may be in a different time zone. One informant described the culture of the NW:

"*There are attitudes that are bred in the culture that you are always available*".

We discovered several reasons why our informants adopted a nomadic worklife. First, they claimed that it was important in order to share skills. For example, technical staff at one location reported that they had a special skill set that would benefit a remote group but they were unwilling to relocate to the remote group location.

Second, a common cited reason for nomadic travel is to meet with workgroups who are distributed. One technical assistant described that the majority of his workgroup is remote and he needs to cater to the group majority. Often, cultural norms of remote teams, wanting to meet face-to-face, motivated our informants to travel to their locations. A designer described:

"*I've had industrial designers hide the phone in the conference room because they didn't want people to call into [the] meeting; they wanted them to attend in person*".

Such a cultural norm was observed during a meeting when someone avoided passing out the telephone bridge number to ensure more in-person participants. One informant mentioned his annoyance at constantly hearing his remote coworkers half-jokingly ask when he'll settle down and move to where they are because of their consistent preference for face-to-face meeting.

Most of our informants explained that they used nomadic practice strategically to establish and maintain face-to-face contact with others. Many of our informants are involved with marketing and business—areas where face-to-face contact for buy-in with clients is crucial. One informant explains that his face-to-face interactions as a NW are critical for "*relationship babysitting*". Informants reported that traveling for face-to-face interactions was worth it for starting relationships as well as establishing trust, similar to what Rocco [38] found for distributed teams. One informant involved in the business side of the company describes how his nomadic worklife supports his ability to gain agreement with colleagues:

"*Traveling to trade shows, talking with VPs, having discussions with university technologists…we try to determine if their interests align with our interests. Once a deal takes place, there is a lot of investigation, talking to competitors, talking with VCs, attending Global Inc. internal meetings for…gaining some sort of agreement*".

The next sections will present our results from our ethnographic investigation and we discuss in detail how properties of infrastructure affect NWs.

5.1. Integrating with the local infrastructure

At Global Inc., the laptop is the NW's key resource. It often serves as the only conduit for interactions with distributed colleagues (e.g., via email or instant messaging) and for work, e.g. through storing documents. The mobile office consists of the laptop but is also an assemblage of other devices, such as Blackberrys, cell phones, and printers. Informants referred to their laptop as "*my life blood*" and "*the cornerstone*". One NW described:

"*Keep in mind that Global Inc.'s got about* 70% *laptops…In fact, when I ask people where's my office, I point to my backpack and say, 'That's my office*".

The reliance on laptops at Global Inc. is in contrast to the finding of Perry et al. [23] whose informants used mobile phones much more frequently than laptops. The NW must, however, assemble a collection of resources in addition to the laptop in order to replicate the office at any location. The extra work that nomadic workers have to deal with, compared to other less

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mobile workers, involves the assemblage and maintenance of this mobile office. This assemblage depends heavily on the particular characteristics of the local infrastructure.

The NW depends on this local infrastructure – such as network connectivity or cell phone reception – in order for their mobile office to function. NWs differ from workers primarily working in one site in that they cannot fully rely on the organization to provide them with a local office or even a stable set of artifacts. Instead, it is the NW's burden to carry as much of their office with them as possible and, when that is not possible, to search for the resources themselves in order to assemble their office. Our informants report that to be self-sufficient they carry devices that enable the mobile office to plug into the local infrastructure such as power plugs, or cell phones that match the local standard (e.g. GSM), as well as carrying portable printers, backup devices, batteries, SIM cards, and paper artifacts.

No matter what new environment they are in, NWs immediately seek to create a portable office that is as complete as possible so as to be self-sufficient. NWs carry components to provide redundancy: a way to contact others in case one means cannot work. The portable office assemblage enables NWs to maintain continuity in their work and deal with contingencies they encounter as environments can be unpredictable. For example, the wide coverage of BlackBerrys proves useful in customer sites as one NW described:

"*Usually, I get no access at a client's site. The only access I can get is via modem, which is pretty much impossible these days. Typically, my only connectivity is through a BlackBerry device*".

While NWs cannot entirely depend on the organization to provide them with a stable set of resources, they nevertheless seek out particular environments in company sites equipped with certain sets of utilities to which they can connect. These environments have components already integrated into the infrastructure, or as Star and Ruhleder describe, are *built upon an installed base*. NWs can then connect their mobile office into these environments creating an overall assemblage that resembles more of a complete, and perhaps 'ideal' office. For example, conference rooms offer resources that are compatible with local infrastructure in a centralized location: power, network connectivity, whiteboards, phones, tables, seats, and projectors. Cubicles are convenient in providing power and connectivity. Both forms provide varying degrees of privacy. Traveler's workstations dedicated to the NW used to exist. One NW explained:

"*Traveler's Workstations' that's what they were called. Now what they were was a room somewhere, and be it like a double-cube sized deal, or it might be a stack of four cubes in a row where you show up and there was a PC and a printer and a wide-band connection. And you could just sit down at the computer and type your way onto it*".

Traveler's workstations provided a nearly complete office. However, they have largely been phased out at Global Inc. Management wrongly assumed that the laptop is the complete office and thus everything else is redundant. That is, once laptops with wireless connectivity became mainstream, it was believed that people did not need a dedicated space with a chair, desk, monitor, wired connection and connected to a local printer setup. Management at Global Inc. neglected to consider the role of infrastructure—both technical and physical.

In particular management failed to understand two properties of infrastructure. First, it is *built upon an installed base*. Mobile offices must be compatible with the underlying infrastructure. They did not take into account that NWs may have incompatible equipment. The infrastructure's installed base was built upon a legacy that assumes that all workers are locally mobile, not mobile across different, geographically dispersed sites. Second, they did not consider that local infrastructure is an *embodiment of standards*. For routine users, they can easily connect to local infrastructure but nonroutine users must understand the local infrastructure that they need to utilize so that they can design their mobile office to be compatible with it.

5.2. Physical infrastructure

Physical infrastructure is important to NWs as well as the technical infrastructure. Our informants frequently spoke of needing a physical layout for work that also included ergonomic considerations. One informant explained:

"*Your own cabinet and drawers, you have the computing facilities to handle your work, a docking station, own setup of your computer, which means you have a place to put your notebook in the right position, your own keyboard, headset. The virtual office usually doesn't have the things to meet your needs. Those are the basic things you expect. One of the most important things is the chair; you need the chair to be a setup according to your needs*".

Though not a material resource, NWs often seek privacy in order to work. In addition to concerns including data security at different sites, NWs also seek privacy in their workspace and surrounding area so as to be free from distractions. Whereas it is true that any worker can be affected by interruptions, NWs have a unique concern that they lack a physical space where they can retreat to that is quiet and private. They are often relegated to public spaces such as cafeterias. One NW described how when trying to work in a public place he is surrounded by people walking around him. (He uses a privacy filter screen with his laptop on flights).

Privacy is not always easy to find for meetings when one lacks an office. We observed informal meetings transform into formal meetings by moving from the cafeteria to the conference room. Meetings often involve call-ins where people need to speak loudly.

Some NWs enjoyed anonymity, citing the ability to concentrate on their own work in between meetings during "dead-time" [23]. Even though cubicles may provide a semi-private space to work, we discovered that NWs may be distracted by discussions concerning work that is not relevant for them. Two NWs described their experiences with cubicles:

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"*The other disadvantage I have of being in cubicles like in* [–] *…people that are very loud around me and not all in the same business segment that I'm in. So, while I'm on the phone with customers they might be cursing or they might giving pricing information or they might be giving out information that my customer shouldn't be hearing*".

"*A cubicle in an active area…you're in a little bitty place to work and there're all these people buzzing around the computers, 'Hi, where are from?' 'I'm from here.' OK. 'Let me tell you about my grandson.' All this kind of junk*".

These cases illustrate the property of *embeddedness* of infrastructure. Infrastructure is attached with other structures, both material and social. Privacy is a social quality and the degree of privacy is embedded into the physical infrastructure. Thus, it is a challenge for NWs to find physical infrastructure that is embedded with appropriate social as well as physical qualities for work.

NWs face competition with local workers for the use of physical infrastructure. For example, without a dedicated office, our informants report that they constantly must search for power for their laptop. Yet buildings often do not supply enough public power outlets:

"*There's two power outlets in the entire cafeteria…Usually what happens is somebody sits down there to eat breakfast or lunch, who isn't interested in the power, but they've got the power plug hogged up. It's just nuts. It's as bad as the airports*".

Competition also exists for conference rooms. Global Inc. has a conference room reservation system, which its employees can use to gauge which rooms are available. However, observations of local practices at Global Inc. reveal that conference rooms are actually used without regard for NWs. Conference rooms are regularly booked full in Global Inc., but reservations often go unfulfilled. One informant described:

"*We were scrambling around for a conference room.⟨ chuckles⟩ people keep reserving conference rooms but never use them so we just kind of walk around looking for one that's empty". In the rare cases where someone has booked a room and arrives to claim the reservation, they can "kick people out*".

Indeed, we saw many local workers in meetings, sometimes with two people taking up an entire room that could house ten or more. This case illustrates the property of infrastructure as *linking with conventions of practice* at the local site. Local workers are not aware of the needs of NWs and thus use resources without an awareness that resources are limited and need to be shared with "outsiders" or nonroutine users.

5.3. The human infrastructure

Not only must the NW integrate with physical infrastructure as we described, but they also must integrate with a human infrastructure of IT support, managers, coworkers and administrative assistants. Because they are temporary visitors at a site, NWs face problems tapping into the site's human infrastructure for support. NWs need to be aware of the human infrastructure in each location. For example, one NW researcher who develops hardware prototypes needed a certain brand of remote control for a device he was implementing, so he contacted a multimedia integration engineer named Gary:

"*You know, I come out of the lab and…we've got a gang there. [But] when you're out of the way from the site, it's a lot more difficult to qualify the resources that are available to you…Good buddy Gary that's here…he didn't have any remotes that…resembled what I was looking for. Usually he's a pretty good resource but it took me* 3 *years to find out he was here!"*

It was by sheer chance he found Gary: "*Talking to a guy in Oregon, that knew a guy in New Mexico, that knew Gary here*".

In another case, an informant asked an admin to help find another admin to get office supplies:

"*I've asked my admin to locate…a group level connection down here where I could find an admin who would be willing to let me basically utilize their resources just for like basic office supply type stuff*".

Unlike local workers, NWs thus face challenges in not knowing the local human infrastructure, e.g. which persons can provide support. This was the case even when our informants were nominally in the same organization. In many of the locations to which NWs travel, local workers have formed communities of practice [12] from which they use as a resource for information seeking. However, NWs typically do not stay at a single location long enough to (1) uncover the implicit, "invisible" communities of practice and (2) become active members of a community of practice. At Global Inc., most informants noted that they did not interact with other NWs; this might have proved useful to allow informants to share common "practice", or best practices on adapting to certain locations' infrastructures.

A property of human infrastructure is that it must be *learned as part of membership to a community* [10]. Again, it is a challenge for NWs to become members of a community of practice when they are not physically present for very long at different locations.

5.4. Use of infrastructure to integrate with others

Star and Ruhleder discuss how social arrangements are embedded into infrastructure. Here we focus on the challenge of using infrastructure to synchronize with others across time zones and to maintain awareness of colleagues. The NW is expected to be available with colleagues almost continually due to different time zones and meeting schedules. NWs depend on the infrastructure to enable them to communicate and remain aware of their colleagues' current activities. Otherwise, as some informants report, NWs risk becoming "invisible" or marginalized in the organization.

All of our informants reported that they work in multiple projects, with different networks of people. Therefore, NWs must synchronize to communicate and coordinate with multiple sets of people who may themselves be NWs traversing different time zones. One nomad described his odd schedule:

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"*My first meeting was* 4 a.m. *US time with a meeting I had to do with my Israeli team*…5 a.m. *to* 6 a.m. *was a meeting with a project team where some of the people are in Arizona. Some of the people are in the UK and me over here and two people from Israel*".

Despite these early morning hours for meetings, this NW was still expected to attend a dinner later in the day locally with others. Thus, NWs must manage communication both with remote and local colleagues, who may be in different time zones. Different cultures pose challenges for time synchronization. For example, one nomad reports that in Asia people work late, and when there he may get a call at 11:30 p.m. at night.

However, sometimes due to problems such as those we discussed earlier, NWs fail to connect to the technical infrastructure, and consequently cannot make meetings and contact colleagues with critical information. To remote colleagues, it is not clear what the problem is. Our informants report that remote colleagues often falsely attribute the problem to the NW colleague not putting in the effort to communicate and not in fact to problems in integrating with the technical infrastructure. This is an example of the relational aspect of infrastructure. To the NW, infrastructure becomes *visible upon breakdown*, whereas to remote colleagues, the infrastructure breakdown is not visible. This can lead to misattributions concerning the behavior of remote colleagues.

It is not only colleagues with whom NWs must synchronize but also with remote organizational practices. For example, backups, as managed by their local IT support, are especially not suited to the nomadic schedule. Global Inc. has regular automated backups on the laptops they issue. The backup time is set with respect to one's home office time zone. This can be terribly inconvenient for NWs, as one described:

"*[Backups] all happen at the wrong time. You're in the middle of a presentation or at home on a dialup line and it says, 'Do you want to backup your whole computer'"? Another NW explained: "It ties up a lot of bandwidth to do the backup and then if I want to whip my laptop off, stop the backups, and go visit a customer you know…it's a heck of a lot easier for me to just do the backups [myself]*".

Thus, a challenge that NWs face is synchronization with other colleagues and with organizational practices, as they traverse through different time zones. Infrastructure that is visible upon breakdown to one colleague may not be so to a remote colleague; this can lead to misattributions among remote colleagues.

5.5. Infrastructure as local knowledge

Through experience, people can learn subtle practices to obtain local resources or to learn how to use the local infrastructure. This experience is often gained implicitly through physical presence. Again, this illustrates Star and Ruhleder's property of infrastructure as *learned as part of membership*. However, NWs, constantly in transit among different locations, spend little time learning the nuanced practices surrounding resource utilization in a particular location. One critical aspect of this local knowledge is in understanding where the working resources are. The local population in contrast is generally aware of where the working resources are (or they know who to ask). We followed one NW informant as he went to one conference room, tried Ethernet plugs and then went to another conference room and found a working Ethernet plug on the second try. There are no visible markers that indicate whether a resource is working and of good quality. NWs inevitably waste time checking the "quality" of a resource, as one described:

"*The power guns [in the projector] are burned out in which case your stuff might just come out looking black because you use a lot of blue in your background*".

Existing markers are often less than satisfactory. Printers are firmly tied to a location. One form of marker for printers appears on the laptop when NWs search Global Inc.'s internal network. These markers name the printer's physical location and not the nearby printers. As a point of reference, the Global Inc. campus we observed consists of seven buildings: the longest distance between two buildings is nearly 0.5 miles. A printer far away will not be helpful for a NW. After some time, NWs typically accumulate a long list of Global Inc. printers set up on their computer. They must continually change their default printer, or, as one NW complained, he would be printing to another site. Global Inc. also has paper cards located above or next to the printer identifying their IP, location and name. However, many cards are outdated as one NW described:

"*So there's all these dead-letter addresses. So you go into a place and there's a little routing tree that says on* 4–3 *of R&B there['s] a color printer here, a laser printer here, a Tektronix over here, right? So you send print to it, and then you get over there and you find out the printer was cannibalized 6 months ago, so it goes into a dead-letter file, but it doesn't give you a blurb that says, 'Sorry, nothing here'*".

Who is maintaining these markers? The local IT staff have set up markers but have little incentive to maintain them because they serve primarily local members, and printer setup is typically a one-time operation. NWs are disadvantaged and as one described, he must "*wander around and take a piece of paper and write down the printer address*". As a result, some informants reported that they prefer to purchase portable printers that they use in hotels or at work sites and then dispose of them like "razor blades", rather than rely on the company's printers.

These cases also illustrate Star and Ruhleder's properties of *embeddedness* and *transparency* of infrastructure and shows how nonroutine users are unaware of the coordinated components of infrastructure. As there were no visible markers to indicate where the printers are or which Ethernet plugs work, the aspects of the working infrastructure are invisible to those who are not local.

A particular case of how infrastructure lacks transparency to nonroutine users is shown through their experiences with wireless networks in different locations. Throughout our interviews, wireless was seen as something quite different from

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seamless. Because of its invisibility, NWs saw wireless as a black box and were confused as to why it did work one day and not another. How does one "hunt" for wireless? Our informants described:

"*When I get it to work, it's terrific, but I can spend…20 min and somehow luckily succeed with no clue in my own mind which magic step it was*".

"*But now it's like a, 'Take your best chance and see if it works.' If it doesn't work you wind up being frustrated and you say, 'Heck with it, I'll deal with it later*".

"*They don't always stay connected…and a lot of people have that problem, no one's really explained to me why or how to solve it*".

"*You can be sitting right under a wireless modem and still not…get connected*".

How to debug the wireless infrastructure is particularly difficult for NWs—they do not know whether the fault lies in the environment, the latest automated updated from IT or in their own laptop's particular configuration. Most NWs end up giving up and finding alternative resources (e.g., Ethernet cables in conference rooms, which require no setup). It is the NW's burden to uncover the transparency of the infrastructure and debug it. They cannot afford to have their laptop away being fixed, and IT support is unlikely to be able to debug remotely because of the possibility that the problem is site specific. Some informants describe:

"*Wireless has gotten better, but the big pain is that different ISPs require that you pay for the hotspots. $9.95 for a spot of 5 min is painful*".

"*Where it is actually pretty difficult is when I am in a customer's building and the reason for that, it's similar for people coming to Global Inc. in that most of the internal networks are all firewalled. For anybody to come in and try to VPN out, their network is usually not possible. It would be nice if there was a technology that allowed …us to VPN in when we are at their sites*".

When NWs travel to sites outside Global Inc. (e.g., customer companies), they face the additional challenge of dealing with the infrastructure property of *embodiment of standards*. Going to coffee shops, NWs have to deal with multiple hotspots due to the lack of a single unified provider. Moreover, trying to use VPN and connect to their own networks (e.g., to check email or access networked computers) from customer sites can be especially frustrating as each site has their own policies and rules for visiting clients' use of internal networks.

6. Discussion

It was our intent in this paper to bring to the forefront the discussion of pervasive computing design, a consideration of how mobile users must grapple with different local infrastructures. For local users, through experience and communication with peers, they have learned to understand their local infrastructures. It is more of a challenge for extremely mobile workers whose use of local infrastructure is nonroutine. The work life of contemporary NWs involves challenges beyond the usage of any individual mobile device.

One main challenge for NWs is in understanding and adapting to the local infrastructure in order to utilize the local resources. There is not any single infrastructure to adapt to, but rather multiple and different infrastructures. The local infrastructure involves not only technical challenges, e.g. finding power and connectivity for their laptops and cell-phone reception, but also physical infrastructure is needed such as a space with a desk or table or a conference room. Some resources are nonmaterial, such as privacy. There is also a human infrastructure with who the NW must integrate, consisting of people such as administrative assistants, IT support or technical experts. Often NWs must compete for resources with others (e.g. space), and often the locations of these resources are unknown or not readily available. These resources are sometimes sparse and vary in quality and situational appropriateness.

NWs must also depend on the local infrastructure to be able to interact with their coworkers, whether they are local or globally distributed. NWs depend on infrastructure not only for data-sharing and communication with colleagues but they depend on infrastructure to provide awareness, and to be aware of colleagues, who are local and also remote.

6.1. The interplay of technical, physical, and human infrastructures

Our study has shown how the technical infrastructure is intricately woven into human and physical infrastructures. However, discussions about infrastructure in pervasive computing generally focus solely on technical infrastructure. We now return to Star and Ruhleder's properties of infrastructure and discuss how our findings of NWs practices relate to these properties.

Infrastructure is embedded within other structures. In particular, it is often embedded within social arrangements that affect practices such as competition for resources or coordinating with organizational practices. We also found that privacy is embedded within physical and human infrastructures. NWs must find the appropriate physical infrastructure in which to use a mobile office. Knowing how a mobile office can be integrated into a local infrastructure involves understanding properties such as embeddedness and how infrastructure is built upon an installed base. Components such as noise cancellation headphones can help to integrate with local infrastructure, yet these then become additional components to include with the mobile office, and thus additional things to transport.

Our study points to the value of having traveler habitats—the very thing that Global Inc. and other large companies have discontinued—that can meet requirements for ergonomics and privacy, along with providing useful assemblages with which

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the NW can easily integrate with their own mobile office. However, management at Global Inc. failed to understand that infrastructure is built upon an installed base, and that without providing that installed base, NWs may not be able to connect to an infrastructure that is based on different standards than that of their mobile office.

Many of the properties that Star and Ruhleder defined for technical infrastructure apply to human infrastructure as well. For example, knowing who to find for local technical support is a property of learned membership. Reach and scope are also properties of human as well as technical infrastructure—these refer to knowing what local work roles are and who can assist in which capacity. Infrastructure is embedded into social arrangements at local sites that are part of the human infrastructure.

A challenge for NWs is to maintain awareness of colleagues at remote locations even though in different time zones. Maintaining such awareness involves an interplay of technical and human infrastructures—knowing who is in which time zone and how one can interact with them through technical means. Our informants related to us the difficulty in maintaining interactions—meetings are generally not scheduled with consideration of the NW's current time zone. One design feature that can make an aspect of human infrastructure more visible is a time zone preference that is sent to colleagues with who one collaborates. This notification can state location but also preferences as to what is an acceptable time for being accessed. Another design feature that we envision is a scheduling system that keeps track of time zone histories when members attended previous meetings. The burden of unwieldy meeting times (e.g. 4 a.m.) can then be more equitably distributed (or negotiated) among meeting members so that the burden does not always fall on the NW. Internal directory services need to become dynamically and remotely updatable (possibly via mobile devices) to account for the fact that not everyone is at their "home" office.

6.2. Developing local knowledge: Towards communities of practice for nomadic workers

NWs at Global Inc. largely work in isolation of each other. Our study showed that NWs need others to support them in their mobile work, for example, the human infrastructure at local company sites and remote colleagues. However, NWs are faced with the challenge of acquiring local knowledge about infrastructure that is ordinarily tacitly gained among local workers. The properties of infrastructure that we found are often learned among local workers must be explicitly acquired by NWs.

A way that NWs can acquire such local knowledge is through communities of practice [12]. By forming communities among NWs, this can help solve many of the problems that nonroutine users of infrastructure face. Communities of practice for NWs can involve global social networks. For example, wikis, blogs and forums can be ideal media for disseminating "tacit" knowledge such as how to easily set up wireless connectivity at a particular site. Already some online communities[3] cater to NWs in general by offering travel tips. However, organizations with large numbers of NWs would benefit from internal company sites that offer specific information concerning infrastructure properties. Online organizational communities would also benefit NWs by building and maintaining communities of practice. Through legitimate peripheral participation of NWs in communities of practice, tacit knowledge of local infrastructure practices can be shared [12].

We believe that local knowledge can benefit NWs in learning the infrastructure properties of transparency, knowledge of reach and scope, knowledge of what can provide an installed base, linking with conventions of practice, and the nature of embeddedness. These types of infrastructure properties are generally learned through tacit knowledge among local workers and are often unique to an organizational site. For example, local knowledge includes knowing which local workspaces can provide an installed base for the mobile office. Local knowledge also concerns understanding social properties of infrastructure, such as privacy and usability concerns. Some nomads prefer to situate themselves where they have maximum contact with others to heighten their visibility in the organization, and this also requires local knowledge. It took one NW three years to find a multimedia integration engineer to help him negotiate the local infrastructure. Through local knowledge the NW could understand the reach and scope of the human infrastructure to know who could help him with his concern. To local workers, many aspects of infrastructure are transparent, such as knowing how to access the wireless network or knowing where working resources are. For these local workers, the knowledge is often shared tacitly such as observing others who use working resources. Yet to NWs, this is knowledge that must be externalized for it to be known.

NWs are often not part of the local community of practice where such knowledge is often shared. For tacit knowledge to become shared, it must be externalized to become explicit knowledge. This leads us to our next discussion, on how infrastructure can become visible for its properties to be learned.

6.3. The need for infrastructure to be visible

Infrastructure is generally invisible to people when it works as expected. However, for the NW, technical, physical and human infrastructure is always in the foreground. The NW must hunt for resources when they arrive at a new site, sometimes even at a site that they have previously visited, as printers may have moved, the wireless network may have changed, rooms may be reconfigured, and so on. In contrast to Mark Weiser's dream of computing receding into the background [5] we found that the very users of ubiquitous computing need infrastructure to be visible, and not only when they encounter it initially at a new site. As a result, NWs become "do-it-yourselfers", forced to become adept at diagnosing and fixing their own tools.

[3] At the time of this writing, there are communities such as.

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Infrastructure could be made visible in many ways, for example, through updated maps or indicators of locations of key resources at a site. GPS portable devices could help NWs navigate through new sites via augmented reality software.

Weiser argued that infrastructure and tools should be invisible so that people can focus on their task and not the infrastructure [5]. We argue that this vision may apply to local routine users of infrastructure but not for people such as NWs for who much infrastructure use is nonroutine. Our argument for making infrastructure visible differs from Chalmers and Galani's [39] notion of seams in wireless devices, i.e. the gaps or breaks in functionality as the user moves across areas and changes devices. Chalmers and Galani propose that seams can be a resource in design, and therefore they could be made visible. Our focus instead is on making *infrastructure* visible for nonroutine users, so that its properties become known and it therefore becomes transparent and easy to use.

While the issue of invisibility has been questioned lately in terms of urban environments [6], we believe our study of NWs highlights the need to also consider the question of infrastructure's visibility in the *workplace*. At first glance, the workplace may be viewed as a static infrastructure in which local knowledge is effectively shared among its inhabitants through traditional means such as communities of practice or occupational communities [40]. As our results show, the increasing pervasiveness of information technologies has increased our reliance on such traditional means of knowledge sharing (e.g. printer locations, support staff, wireless connectivity spaces) in order to accomplish work in local infrastructures. Moreover, the increasing pervasiveness of IT has *enabled* NWs to arise as new, albeit transient, inhabitants in these local infrastructures. Thus, ubiquitous computing has created at the same time infrastructures whose inner plumbing are less visible and yet also new workers whose need is ever more pressing for that plumbing to be visible. Thus, those who subscribe verbatim to Weiser's vision need to consider that infrastructures must accommodate *different sets of people*, even in the workplace.

At this time however, infrastructure remains invisible to many nonroutine users and must be discovered. We have not yet reached Weiser's vision of seamlessly integrated computing where components are compatible and infrastructure always functions as designed. We argue that infrastructure needs to be made visible for nonroutine users. Knowledge of infrastructure must be externalized in order for it to be shared and thus learned. As technical infrastructure is intertwined with physical and human infrastructures, and as NWs utilize aspects of all types of these infrastructures, means to increase the visibility of infrastructure need to be explored, whether through social means such as communities of practice or other technical or physical means.

7. Conclusion

Drawing upon Star and Ruhleder's properties of infrastructure, we have shown how nonroutine users of infrastructure are affected. To nonroutine users of infrastructure, they lack the knowledge of infrastructure properties such as transparency in its use, an awareness of reach and scope, and the nature of its installed base. Whereas infrastructure becomes visible upon breakdown to nonroutine users, it remains invisible in the background to routine users as long as it works. In other cases, infrastructure breakdown affects remote collaboration though its breakdown is not visible to remote collaborating partners. NWs lack the local and tacit knowledge that routine users of infrastructure gain through experience and sharing.

Star and Ruhleder highlight that neither the human nor non-human component of infrastructures should be predominant. Our study notes that when certain human components become dynamic, unchanging non-human/human components become a less than ideal fit. Infrastructures are shared, as Star and Ruhleder note, but how does one share infrastructure meaningfully when certain populations shift in and out? What does it mean when *conventions of practice* cannot be so easily passed on? What does it mean when NWs routinely use certain work site's infrastructures, but only in limited time periods? By the time NWs return back to an old site, they find things have already changed. All these questions seem to call for infrastructures that are adaptable and malleable. Nonetheless, it would be a mistake, for example, to simply design infrastructure to accommodate NWs—this would make local work painfully inefficient and explicit. However, for example, hybrid infrastructures that benefit both types of workers may be ideal: office spaces that can be rapidly configured for privacy or meetings; increased awareness tools that can create better face-to-face opportunities for both locally mobile and NWs; tools for more effortless marking by the local populace (e.g., to mark broken projectors or disable ethernet slots); and providing devices for NWs to better uncover infrastructure (e.g., WiFi detectors). We do believe that the number of NWs will continue to grow and at some point, designers will have to confront the challenge of making infrastructure visible.

Through this study we hope to expand the topic of infrastructure challenges into the discussion of pervasive computing design. Pervasive computing involves not only a set of devices but an assemblage such as a mobile office that must be integrated into local infrastructure. Further, technical infrastructure is interwoven into human and physical infrastructures and these all affect pervasive computing use. There are numerous social and organizational challenges in pervasive computing and we hope our study can spark ideas for further research.

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