Woes, Workarounds, and Wishes of Users Living in a Multinetwork Reality

Md Nazmul Hossain
mh2752@nau.edu
Northern Arizona University
Flagstaff, AZ, USA

Morgan Vigil-Hayes
morgan.vigil-hayes@nau.edu
Northern Arizona University
Flagstaff, AZ, USA

ABSTRACT

Despite efforts towards pervasive, high-speed broadband connectivity, users worldwide continue to experience a persistent *multinetwork reality*–a reality of intermittent Internet access over multiple networks of varying capacities across space and time. In this late-breaking work, we investigate the challenges users face while using different Internet-based services and the mitigating strategies they adopt to overcome those challenges in a multinetwork reality. In addition, we also investigate how users envision software-based interventions that might augment their existing strategies and help them better manage their activities in a multinetwork reality. Finally, based on our findings from a qualitative analysis of semi-structured interviews, we explore a two-dimensional design space defined by cognitive and resource costs and discuss directions for future work.

CCS CONCEPTS

• **Human-centered computing → HCI design and evaluation methods**.

KEYWORDS

digital divide, multinetwork reality, broadband connectivity, qualitative analysis, design space

ACM Reference Format:

Md Nazmul Hossain and Morgan Vigil-Hayes. 2023. Woes, Workarounds, and Wishes of Users Living in a Multinetwork Reality. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems (CHI EA '23), April 23–28, 2023, Hamburg, Germany*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3544549.3585795

1 INTRODUCTION

As the Internet and daily activities of our lives intertwine, the need for pervasive broadband Internet connectivity becomes increasingly apparent. However, despite significant efforts, resources, and the emergence of cutting-edge wireless communication technologies over the years (e.g., satellite constellation networks, 5G, WiFi), achieving pervasive broadband connectivity remains a holy grail in modern telecommunications due to a multitude of factors [7, 8, 10, 11, 37–41]. As a result, a significant portion of the world's population (including economically developed countries) access the Internet using multiple types of network connectivity, often with intermittent coverage and inconsistent performance capabilities [7, 8, 10, 11, 37–39, 41]. Living in a reality of intermittent Internet access over multiple networks across space and time, or *multinetwork* reality, often brings unique challenges to users and can force them to adopt mitigating strategies.

Users experience an increasingly multinetworked reality as broadband and Internet of Things deployment efforts seek to expand network coverage and capacity with a myriad of technologies, including fiber optic cables, 5G with millimeter wave capabilities, and low-powered radio [1–3, 13, 21, 22, 26, 28, 29, 32, 36, 42, 44]. Particularly in periurban areas, users must navigate livelihoods that expect certain levels of network connectivity while traversing spaces that may not always provide connectivity that matches these expectations. For instance, a business consultant living in an area that only supports DSL connectivity at home may not be able to take client meetings via Zoom during times when others are using her home Internet; she must either schedule bandwidth-intensive work to take place when there are fewer demands on the network or mobilize to a space where her mobile broadband has enough capacity to enable the call. For billions of people, the negotiation between network capacity and the requirements of work, social connection, and entertainment is a fundamental reality [9, 24, 30, 31, 33, 34]. However, there are currently very limited tools to support users in explicitly managing these negotiations. Moreover, as evidenced by years of long-standing digital divide issues worldwide, uneven deployment of varying capacity network connectivity is likely to be a persistent norm [8, 23, 24].

In this work, we focus on interviewing individuals who navigate multinetwork realities in Flagstaff, AZ, to answer the following research questions:

RQ1: What existing practices do users adopt to manage online tasks in multinetwork environments?

RQ2: Based on existing connectivity management practices and challenges, what opportunities exist for tools that can explicitly assist users navigating through multinetwork environments?

2 RELATED WORK

Our work relates to two bodies of research: (1) characterizations of how people in the Global North and South manage their information needs and online activities without ubiquitous, high speed Internet connectivity; and (2) user-facing techniques for managing network resources.

Wyche et al. characterize a "deliberate interaction" style that is used by individuals in Nairobi, Kenya to accommodate challenging Internet infrastructure. This involves users making time to go to public Internet cafés and deliberately planning out online time in

CHI EA '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9422-2/23/04.
https://doi.org/10.1145/3544549.3585795

order to maximize its use. In 2017, Dye et al. examined how Internet users in Havana leveraged WiFi hotspots to increase access to the Internet across space and time [19]. This body of work points to how connectivity can render "spaces into places" and how community efforts can be leveraged to extend connectivity beyond space and time by allowing users to connect to Internet services and interact with content on each others' behalf. Other notable works by Dye et al. also highlighted how users adopt mitigating (often unconventional) strategies when Internet connectivity is not pervasive and unconstrained [15–18, 25]. Finally, an exploratory interview study by Erickson and Jarrahi examines how mobile knowledge do the work of infrastructuring to articulate gaps between different information infrastructures in New York City and South Carolina [20]. Importantly, they reify observations by Dourish and Bell [14] and Chalmers et al. [4] that "seams" between infrastructures can be generative for the users who navigate through them, and lead to innovative, problem-solving practices.

Our work also relates to system design work that proposes user-facing techniques for managing network capacity [6, 44]. Chetty et al. deployed uCap with users in the United Kingdom, South Africa, and India [6]. Through deployment, Chetty et al. reveal that designing network management tools that align with users' everyday interactions with their home network is a substantial design challenge with significant space for improvement, especially surrounding the challenges of coordinating the social aspects of resource management. More recently, Vigil-Hayes et al. examined user responses to interfaces that helped translate network capacity to application capabilities [44]. This work highlights the general need for tools that help users navigate through networks of various capacities over space and time, but it does not explore users' existing strategies for accomplishing this nor how software tools might facilitate these strategies.

3 METHODOLOGY

We used a qualitative analysis of interview data to answer our research questions. The interviews were semi-structured and all of the questions were open-ended in nature. In an effort to maximize candid responses from the participants, we asked unscripted and open-ended follow-up questions whenever appropriate.

3.1 Recruitment & Data Collection

We posted paper flyers in public places (e.g., coffee shops, libraries, marketplaces) around Flagstaff to recruit potential participants. We also reached out to colleagues and acquaintances from work living in Flagstaff through a word-of-mouth approach who were known to have experienced Internet connectivity issues. Ultimately, we recruited seven adult participants living in or around the city of Flagstaff for the interviews.

We allowed each participant to attend the interview individually in person at a convenient public place or via private Zoom meetings. Author MH conducted all interviews individually. Out of the seven participants, four participants attended their interviews in person, and three attended their interviews virtually via Zoom. All interviews were audio recorded for transcription purposes after receiving explicit approvals from the participants via IRB-approved consent forms. At the end of each user interview, the participants completed an online survey containing demographic and technology usage questions.

3.2 Participant Demographics and Technology Habits

Table 1 presents demographic information associated with the interview participants. First, the mean age of the participants (Female = 2, Male = 5) is *30.14 years*, with a standard deviation of *11.19 years*. The participants came from diverse racial backgrounds – one (P1) identifying as American Indian or Alaskan Native (AI/AN), two (P2 and P4) identifying as White (Caucasian), two (P3 and P7) identifying as Asian, and two (P5 and P6) identifying as of some other race, ethnicity, or origin. At the time of the interviews, all the participants were either enrolled in a college degree program (undergraduate or graduate) or had completed a college degree program (undergraduate or graduate). In terms of place of living, the participants also varied widely. For example, while two of the participants (P1 and P2) were living in mostly rural areas, three (P4, P5, P6) were living in mostly urban areas, one (P3) in a suburban area, and one (P7) in a completely urban area. As the city of Flagstaff and most of its surrounding areas lie in a high-altitude mountainous region, the landscape, geography, and population density can vary substantially across a relatively small area. All seven interview participants described themselves as frequent internet users - becoming online at least once or twice within an hour for any purpose.

3.3 Data Analysis

We primarily used descriptive statistics for analyzing the survey responses. We analyzed the interview data with a *grounded theory* [35] approach. First, Author MH transcribed each interview *in verbatim* from the audio recordings. After that, they developed open codes from the interview transcripts. These codes were reviewed by Author MV who made suggestions to the original coder for additional codes or sought clarification on any of the existing open codes. Next, both authors derived axial codes collaboratively based on the open codes developed in the previous stage.

3.4 Statement of Positionality

Our research team includes two researchers with a combined research experience of 14 years in computer networking and the digital divide using mixed methodologies including quantitative empirical analysis and qualitative methods [27, 42–44]. The first author was solely responsible for conducting interviews. Both authors were involved in analyzing the data. Interview data were interpreted against Internet policies, standards, and rights acknowledged by US national (FCC) and international (ITU) entities. The first author identifies as an educated, Southeast Asian male and a temporary resident of Flagstaff. He acknowledges that his self-identity and positionality may have influenced the interview process.

3.5 Limitations

Our work faced two significant limitations that we plan to address in our future work. First, a short recruitment period led to a small sample size of n = 7. Second, with this sample size, we believe even though we reached a saturation point in discovering the challenges

Participant code	Age (in years)	Gender	Race	Occupation	Place of Living
P1	37	Female	American Indian or Alaskan Native	Food delivery	Mostly rural
P2	51	Male	White	Digital Accessibility Specialist	Mostly rural
P3	26	Male	Asian	Research assistant	Suburban
P4	26	Female	White	Healthcare assistant	Mostly urban
P5	18	Male	Other	Retail service assistant	Mostly urban
P6	21	Male	Other	Not stated	Mostly urban
P7	32	Male	Asian	Postsecondary teaching	Completely urban

Table 1: Participant code and demographic information of the interview participants

and coping mechanisms, we did not reach a saturation point in unearthing user visions for software-enabled supports in multinetwork realities.

4 RESULTS

In this section, we present and explore the themes that emerge as answers to our research questions around mitigation strategies that users employ to manage multinetwork challenges (RQ1) and opportunities for new tools to better support and assist users as they navigate through and work in multinetwork environments (RQ2).

4.1 Existing Strategies for Managing Multinetwork Logistics

Faced with the challenges of living in multinetwork environments, the participants adopted mitigating strategies to get on with their everyday online activities. The primary mitigation strategies revolved around committing extra resources to establish a failover network connection, mobilizing to spaces with better connectivity, and prioritizing and scheduling certain tasks to take place during times when network quality was expected to be high.

To deal with unreliable network performances of their primary Internet connectivity (often home broadband connections), participants reported maintaining and using a backup connectivity plan when required as a failover.

"I prefer WiFi...if that doesn't happen...then, I connect to my mobile Internet." (P7)

A few participants also mentioned using public WiFi as their backup connectivity plan in case of emergencies – from McDonald's WiFi to elementary school WiFi.

"We actually drive to the elementary school out here, sit in the parking lot and use their WiFi [when their home Internet does not work]." (P2)

Participants used mobilization tactics to overcome network connectivity troubles–traveling to public places with WiFi or moving to an area with better quality mobile broadband. One of the participants mentioned using mobile broadband as his primary means of being online and the need to mobilize for better connectivity.

"[Sitting in his car parked in a parking lot]...So, now [I have moved] towards [downtown area to] take this Zoom call...Because I don't have very good Internet at home." (P6)

Whether they were relying on mobile broadband or mobilizing to a different location to use a WiFi hotspot, participants also mentioned using previous knowledge about connectivity across *space and time* to make decisions about where they would move to if they needed to find a better connection. This illuminates an important knowledge about the landscape that people living in multinetworked environments must internalize over time through experience. Conversely, it reveals how individuals new to any area may be particularly vulnerable to the challenges of navigating through the seams between spaces of connectivity without internalized knowledge of connectivity in the area. The mobilization and failover tactics also reveal the financial burden associated with these coping mechanisms. Mobile data plans that have data caps sufficient for every day use can be expensive, particularly in the United States [5]. Likewise, the time, mileage, and fuel costs associated with driving to find the nearest point of connectivity represents tangible resource costs that individuals must negotiate as they search for connectivity alternatives.

Another coping strategy that participants reported was task prioritization and scheduling. On constrained home broadband connectivity, one participant mentioned stopping all non-essential online activities when it was time for a scheduled essential online activity.

"The days where I have Zoom visits [her daughter's online counseling sessions]...I make sure nobody's on the Internet at the time we're gonna do our Zoom." (P1)

When network connectivity completely failed or was absent, a few of the participants mentioned postponing online activities for later or rescheduling them.

"So, in some instances, I go for walks... Like I'll be at Buffalo Park, using my phone and if I'm walking around the [poor mobile broadband connectivity] frustrated me to the point where I'll just turn it off and...I would just save it for later." (P5)

In this case, the coping mechanisms employed have cognitive resource costs as users must keep track of what they wanted to do to make sure they come back to it later. Or, if users are prioritizing particular activities over others, there may be a cognitive burden associated with the decision making, e.g., deciding how to prioritize online activities, which activities to prioritize, communicating priorities with other members of the household.

4.2 Opportunities for Software-enabled Supports in Multinetwork Realities

Our second research question seeks to envision ways to identify opportunities for tools that assist and support the infrastructuring that users do when they navigate through the "seams" between spaces of Internet connectivity [4, 14, 20]. To start addressing the question, we asked if interviewees could imagine software tools that might help them better manage their online activities in a multinetwork reality. Interviewees explicitly envisioned software features that would help them prioritize online tasks and reschedule tasks when necessary.

Participants suggested that having tools that could explicitly convey the capabilities of an available connection would help them better prioritize among different tasks as they moved through a multinetwork environment.

"If there was a status [showing] what I could be doing...Can I just read texts? Can I...scroll on Instagram? Can I watch YouTube videos? Can I take a Zoom call? [It] would be nice if [that information] was built into the applications." (P6)

Indeed, this same participant expanded further about the type of information that might be useful for an interface to provide–specifically, making predictions about the amount of time to expect a task or activity to take given current network conditions:

"I want to download something, and [the tool could] tell me how long it would take to download. So, if I hit that download button, [I would know] this will either take like 30 minutes to download or it's going to take like 5 minutes to download...Having those times would be good because I've been trying to download something and then I ran out of time, and I have to go [reschedule/retry later]." (P6)

Beyond what was explicitly envisioned by participants, our interviews revealed clues to information that might assist users in deciding whether they wanted to engage in an activity, such as how frequently they might experience an application to "buffer" in a particular location (P3) or how "choppy" video interactions might be at a particular time and place (P1).

However, tension must be balanced between increasing information about the connection and adding to users' cognitive burdens. For instance, one participant mentioned the need to hide or abstract complex technical details and just present the users with the necessary information.

"If I'm using Discord or something, I need that continuous data stream, right?...as a simple Internet user, my preference would be [that] I shouldn't notice those facts." (P3)

Beyond providing information, our interviews revealed the need for tools to help manage the temporal logistics of poor connectivity. P4, who works as a healthcare assistant, noted some of the temporal dimensions of challenges with handling calls from patients.

"The Internet's bad. I can't tell how many voicemails I have and who's been calling me, and I can't call people back [on the Google Voice app]...I just need [to] be patient and wait till tomorrow and see if the Internet gets better. Or go to the office. But...my office closes at [5 pm] ....[and] I can't go to a public space [sensitive nature of healthcare-related information]. I can't go to the office [because it is closed]." (P4)

A complement to information that conveys the impact of network performance on application experiences also highlights a need for tools to help support the "rescheduling" or planning of networked tasks. Even with information about anticipated network performance, there is a mental load involved with constantly keeping track of which tasks need to be done, when certain tasks can be done, and which ones need to be revisited later (as well as when and where that revisiting should occur). In Section 5, we describe a vision for a tool that might act as a task scheduling assistant for users facing multinetwork realities.

Another opportunity for new tools that support users' navigation through multinetwork environments are tools that help plan mobility through times and spaces with various connectivity capacities. While none of the participants explicitly envisioned tools to support mobility, spatial inconsistency of network connectivity was a recurring theme in participants' responses to questions regarding the challenges of living in a multinetwork environment.

When accessing the Internet, the participants noticed variable connection quality and usability of different types of available networks across different times–ranging from mobile broadband to public WiFi. In a specific case, sudden breakdowns of mobile broadband connectivity render a participant's job tasks challenging (if not impossible) to complete.

"When I'm in the middle of a [food] delivery and I need the information [directions to the delivery address], and the information will go away because I don't have the Internet or something...it just sucks." (P1)

Additionally, connectivity issues such as WiFi dead zones exist even in well-maintained public WiFi networks. These issues can noticeably affect an application's performance.

"There's [a] few specific spots...I don't know why, I don't get the Internet there. Sometimes they buffer the music app I use [music streaming apps], so the music app [stops working] in some part of the campus." (P3)

One of the participants also mentioned experiencing the unreliability of the campus WiFi in some instances, which motivates her to seek better alternatives elsewhere whenever necessary.

"I could go to the library on campus, but I just don't. Sometimes the [campus] WiFi is so bad." (P4)

A final, particularly salient example took place in the middle of the interview, when P6 he mentioned that he had to move from his apartment to a location near downtown to get better mobile broadband connectivity to support the interview (see Section 4.1).

While participants did not explicitly envision tools to help assist them with mobility through multinetworked environments, their existing mitigation strategies of moving to spaces (known or predicted) with connectivity as well as their ongoing challenges with dealing with changes in connectivity *en route* points to a substantial opportunity for new tools that seek to reduce the burden of mobilizing between spaces of connectivity. Tools that provide users with hints about *where* nearest connectivity coverage exists relative to a place of interest, how much it might cost (if not free), or whether they can expect to lose connectivity on a planned route can be extremely useful for reducing the impact of disconnection. In Section 5, we provide a vision for future tools that might assist with mobility through multinetworked environments.

In addition to the spatial and temporal logistics and challenges associated with multinetwork realities, social dimensions also require management. When multiple people or family members share a constrained home broadband network, they often have to prioritize their activities. This requires increased transparency in home network management and planning for connectivity alternatives

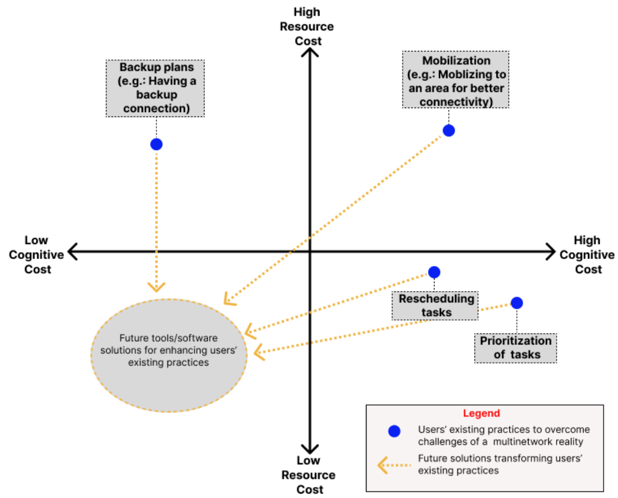

Figure 1: Design space for future software tools that can help users navigate and manage their online activities in a multinetwork reality.

for multiple people. In Section 4.1, P1 details how she *"makes sure nobody's on the Internet"* so her home Internet connection does not experience congestion while her daughter engages with her scheduled counseling sessions via Zoom. In some cases, depending on the tasks' urgency and network requirements, other household members might mobilize to an alternative point of connection (e.g., a coffee shop with WiFi). While there is a strand of work that focuses on home network resource management for multi-person homes [6], tools focused on managing the quality of connectivity for a family using a single home network do not sufficiently address the challenges of managing mobility between different networks or scheduling online activities for multiple individuals based on connectivity and daily agendas. In Section 5, we discuss how tools addressing spatial and temporal logistics of multinetwork realities can be expanded to incorporate social (household) logistics.

5 DISCUSSION & FUTURE WORK

Multinetwork realities will likely persist for a considerable period as ISPs are more likely to focus new infrastructure development in areas that already have foundational telecommunications infrastructure available, leading to a "rich get richer" effect [8, 9, 23, 24, 44]. We can expect these digital inequities to be further aggravated by the continual emergence of new networked applications that require evermore bandwidth and latency guarantees to deliver services adequately. *Thus, it is useful to consider how to design tools that might better assist users in navigating multinetwork environments that are likely to persist long into the future.*

Related work has observed the persistent challenges that "infrastructuring" pose to network users [14, 20, 45] as well as the challenges associated with designing human-centered tools to support network resource management and knowledge [6, 44]. Both strands of work demonstrate a need for tools that help users interact with networks and connectivity in their everyday lives but will potentially bring substantial design challenges.

Tools Envisioned for Future Work. Our examination of opportunities for new tools that might help users with the work of infrastructuring and managing network resources leads us to map opportunities to a design space (shown in Figure 1) where design opportunities appear in spaces that minimize the cognitive load required for infrastructuring work while also minimizing resource costs (e.g., time and financial). Our findings in Section 4.2 cued us to two prominent issues that we envision addressing through software-based intervention tools. First, the wide-ranging capabilities of different networks in a multinetwork reality impose significant cognitive burdens on a user in the planning, performing, and (if required) rescheduling of various networked tasks. Consequently, users in multinetwork realities often face the second issue of needing to mobilize for better connectivity for networked tasks while also juggling a plethora of temporal and spatial logistical constraints in their daily lives. Thus, we plan on developing the following software tools for addressing these two issues in the future.

Task Scheduling Assistant: The scheduling assistant will take a list of "to-do" networked tasks as input from a user and will predict the connectivity requirements for these tasks. As a user moves through their day, the assistant will monitor the available network connectivity and communicate to the user the suitability of a network based on the different capability parameters (e.g., bandwidth, latency, jitter, SNR) for accomplishing the networked tasks from the to-do list through suitable UI design features without putting any unwanted cognitive burden on the user. The user will have the option to either perform a task on the selected network or schedule it to be performed at a later time on a suitable network with the help of the assistant.

Connectivity Map and Route Planner: This tool might display a map of places with available hotspots around the user's current location, coverage areas provided by mobile broadband networks, as well as different capability parameters of the networks (e.g., reported coverage footprint, bandwidth, latency, connectivity dead zones), costs associated with using the networks (e.g., free public library WiFi or complementary coffee-shop WiFi available with the purchase of a cup of coffee), and temporal nature of the networks (e.g., available 24/7 or during certain business hours, any capability variance at certain times). With the help of route-planning functionality, a user would be able to pre-plan and follow a mobilization route through points of network connectivities, enabling them to accomplish different networked tasks along the way as part of a seamless integration with naviagation of other spatial and temporal logistics. To support the social coordination dimension of navigating through multinetwork realities in a household unit, this tool might also support a community coordination feature that would allow members of a household living to coordinate the logistics. For instance, household members might be able to leverage this feature to coordinate their daily agendas and create a shared mobilization plan through and to points of connectivity–allowing them to pull their logistical resources (e.g., transportation, finance) together and efficiently use them in navigating activities in a multinetwork reality. In a fashion similar to the works of Davidoff et al., this feature will also allow adult household members to coordinate spatiotemporal logistics among themselves if any dependent member of the household needs to mobilize to points of connectivity [12].

ACKNOWLEDGMENTS

This project was funded in part by NSF Awards 2145861 and 2122791.

REFERENCES

[1] Aloÿs Augustin, Jiazi Yi, Thomas Clausen, and William Mark Townsley. 2016. A study of LoRa: Long range & low power networks for the internet of things. *Sensors* 16, 9 (2016), 1466.

[2] Martin Bor, John Vidler, and Utz Roedig. 2016. LoRa for the Internet of Things. In *Proceedings of the 2016 International Conference on Embedded Wireless Systems and Networks* (Graz, Austria) *(EWSN '16)*. Junction Publishing, USA, 361–366.

[3] Sherif Adeshina Busari, Shahid Mumtaz, Saba Al-Rubaye, and Jonathan Rodriguez. 2018. 5G Millimeter-Wave Mobile Broadband: Performance and Challenges. *IEEE Communications Magazine* 56, 6 (2018), 137–143. https://doi.org/10.1109/MCOM.2018.1700878

[4] Matthew Chalmers, Marek Bell, Barry Brown, Malcolm Hall, Scott Sherwood, and Paul Tennent. 2005. Gaming on the Edge: Using Seams in Ubicomp Games. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology* (Valencia, Spain) *(ACE '05)*. Association for Computing Machinery, New York, USA, 306–309. https://doi.org/10.1145/1178477.1178533

[5] Becky Chao, Claire Park, and Joshua Stager. 2020. The Cost of Connectivity 2020. https://www.newamerica.org/oti/reports/cost-connectivity-2020/.

[6] Marshini Chetty, Hyojoon Kim, Srikanth Sundaresan, Sam Burnett, Nick Feamster, and W. Keith Edwards. 2015. UCap: An Internet Data Management Tool For The Home. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, USA, 3093–3102. https://doi.org/10.1145/2702123.2702218

[7] Federal Communications Commission. 2018. *2018 Broadband Deployment Report*. Federal Communications Commission. https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2018-broadband-deployment-report Retrieved on 12-26-2021.

[8] Federal Communications Commission. 2019. *2019 Broadband Deployment Report*. Federal Communications Commission. https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2019-broadband-deployment-report Retrieved on 12-26-2021.

[9] Federal Communications Commission. 2019. FCC Mobile Broadband Dataset. https://www.fcc.gov/form-477-mobile-voice-and-broadband-coverage-areas Retrieved on 12-26-2022.

[10] Federal Communications Commission. 2020. *2020 Broadband Deployment Report*. Federal Communications Commission. https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2020-broadband-deployment-report Retrieved on 12-26-2021.

[11] Federal Communications Commission. 2021. *Fourteenth Broadband Deployment Report*. Federal Communications Commission. https://docs.fcc.gov/public/attachments/FCC-21-18A1_Rcd.pdf Retrieved on 12-26-2021.

[12] Scott Davidoff, Brian D. Ziebart, John Zimmerman, and Anind K. Dey. 2011. Learning Patterns of Pick-Ups and Drop-Offs to Support Busy Family Coordination. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, USA, 1175–1184. https://doi.org/10.1145/1978942.1979119

[13] Inigo del Portillo, Bruce G. Cameron, and Edward F. Crawley. 2019. A Technical Comparison of Three Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband. *Acta Astronautica* 159 (2019), 123–135. https://doi.org/10.1016/j.actaastro.2019.03.040

[14] Paul Dourish and Genevieve Bell. 2011. *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing*. MIT Press, Cambridge, MA.

[15] Michaelanne Dye. 2019. Havana's StreetNet: Innovation from Necessity. *XRDS: Crossroads, The ACM Magazine for Students* 26, 2 (Nov 2019), 20–25. https://doi.org/10.1145/3368050

[16] Michaelanne Dye, Annie Antón, and Amy S. Bruckman. 2016. Early Adopters of the Internet and Social Media in Cuba. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (San Francisco, California, USA) *(CSCW '16)*. Association for Computing Machinery, New York, USA, 1295–1309. https://doi.org/10.1145/2818048.2819947

[17] Michaelanne Dye, David Nemer, Neha Kumar, and Amy S. Bruckman. 2019. If It Rains, Ask Grandma to Disconnect the Nano: Maintenance & Care in Havana's StreetNet. *Proc. ACM Hum.-Comput. Interact.* 3, CSCW, Article 187 (Nov 2019), 27 pages. https://doi.org/10.1145/3359289

[18] Michaelanne Dye, David Nemer, Josiah Mangiameli, Amy Bruckman, and Neha Kumar. 2018. The Human Infrastructure of El Paquete, Cuba's Offline Internet. *Interactions* 26, 1 (2018), 58–62.

[19] Michaelanne Dye, David Nemer, Laura R. Pina, Nithya Sambasivan, Amy S. Bruckman, and Neha Kumar. 2017. Locating the Internet in the Parks of Havana. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, USA, 3867–3878. https://doi.org/10.1145/3025453.3025728

[20] Ingrid Erickson and Mohammad Hossein Jarrahi. 2016. Infrastructuring and the Challenge of Dynamic Seams in Mobile Knowledge Work. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing*. Association for Computing Machinery, New York, USA, 1323–1336. https://doi.org/10.1145/2818048.2820015

[21] Steven Gorshe, Arvind Raghavan, Thomas Starr, and Stefano Galli. 2014. *Broadband Access: Wireline and Wireless–Alternatives for Internet Services*. John Wiley & Sons, Hoboken, New Jersey, USA.

[22] P.E. Green. 2004. Fiber to the Home: The Next Big Broadband Thing. *IEEE Communications Magazine* 42, 9 (2004), 100–106. https://doi.org/10.1109/MCOM.2004.1336726

[23] International Telecommunication Union. 2019. *Connectivity in the Least Developed Countries: Status report 2021*. Technical Report. International Telecommunication Union, Geneva, Switzerland. 1–11 pages. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2019.pdf

[24] International Telecommunication Union. 2019. *Measuring Digital Development: Facts and Figures 2019*. Technical Report. International Telecommunication Union, Geneva, Switzerland. 1–11 pages. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2019.pdf

[25] Abigail Z Jacobs and Michaelanne Dye. 2020. Internet-human infrastructures: Lessons from Havana's StreetNet. (2020). arXiv preprint arXiv:2004.12207.

[26] Jansen C. Liando, Amalinda Gamage, Agustinus W. Tengourtius, and Mo Li. 2019. Known and Unknown Facts of LoRa: Experiences from a Large-Scale Measurement Study. *ACM Transactions on Sensor Networks* 15, 2, Article 16 (Feb 2019), 35 pages. https://doi.org/10.1145/3293534

[27] Tarun Mangla, Esther Showalter, Vivek Adarsh, Kipp Jones, Morgan Vigil-Hayes, Elizabeth Belding, and Ellen Zegura. 2022. A Tale of Three Datasets: Characterizing Mobile Broadband Access in the U.S. *Communications of the ACM* 65, 3 (February 2022), 67–74. https://doi.org/10.1145/3462672

[28] Arvind Narayanan, Eman Ramadan, Jason Carpenter, Qingxu Liu, Yu Liu, Feng Qian, and Zhi-Li Zhang. 2020. A First Look at Commercial 5G Performance on Smartphones. In *Proceedings of The Web Conference 2020* (Taipei, Taiwan) *(WWW '20)*. Association for Computing Machinery, New York, NY, USA, 894–905. https://doi.org/10.1145/3366423.3380169

[29] Nils Pachler, Inigo del Portillo, Edward F. Crawley, and Bruce G. Cameron. 2021. An Updated Comparison of Four Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband. In *2021 IEEE International Conference on Communications Workshops (ICC Workshops)* (Montreal, QC, Canada). IEEE, USA, 1–7. https://doi.org/10.1109/ICCWorkshops50388.2021.9473799

[30] Andrew Perrin. May 2019. Digital Gap Between Rural and Nonrural America Persists. https://www.pewresearch.org/fact-tank/2019/05/31/digital-gap-between-rural-and-nonrural-america-persists/

[31] Pew Research Center. June 2019. Mobile Fact Sheet. https://www.pewresearch.org/internet/fact-sheet/mobile/

[32] Zhouyue Pi and Farooq Khan. 2011. An Introduction to Millimeter-wave Mobile Broadband Systems. *IEEE Communications Magazine* 49, 6 (2011), 101–107.

[33] Anique Scheerder, Alexander van Deursen, and Jan van Dijk. 2017. Determinants of Internet Skills, Uses and Outcomes. A Systematic Review of the Second-and Third-level Digital Divide. *Telematics and Informatics* 34, 8 (2017), 1607–1624.

[34] Laura Silver, Emily A. Vogels, Mara Mordecai, Jeremiah Cha, Raea Rasmussen, and Lee Rainie. November 2019. Mobile Divides in Emerging Countries. https://www.pewresearch.org/internet/2019/11/20/mobile-divides-in-emerging-economies/

[35] Anselm Strauss and Juliet M Corbin. 1997. *Grounded Theory in Practice*. Sage Publications, Inc., Thousand Oaks, CA, USA.

[36] Yongtao Su, Yaoqi Liu, Yiqing Zhou, Jinhong Yuan, Huan Cao, and Jinglin Shi. 2019. Broadband LEO Satellite Communications: Architectures and Key Technologies. *IEEE Wireless Communications* 26, 2 (2019), 55–61. https://doi.org/10.1109/MWC.2019.1800299

[37] International Telecommunication Union. 2017. *Measuring Digital Development Facts and Figures 2017*. International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf Retrieved on 12-26-2021.

[38] International Telecommunication Union. 2019. *Measuring Digital Development Facts and Figures 2019*. International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2019_r1.pdf Retrieved on 12-26-2021.

[39] International Telecommunication Union. 2020. *Measuring Digital Development Facts and Figures 2020*. International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2020.pdf Retrieved on 12-26-2021.

[40] International Telecommunication Union. 2020. *Measuring Digital Development ICT Price Trends 2020*. International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Documents/publications/prices2020/ITU_ICTPriceTrends_2020.pdf Retrieved on 12-25-2021.

[41] International Telecommunication Union. 2021. *Measuring Digital Development Facts and Figures 2021*. International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2021.pdf Retrieved on 12-25-2021.

[42] Morgan Vigil, Elizabeth Belding, and Matthew Rantanen. 2016. Repurposing FM: Radio Nowhere to OSNs Everywhere. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (San Francisco, California, USA) *(CSCW '16)*. Association for Computing Machinery, New York, NY, USA, 1260–1272. https://doi.org/10.1145/2818048.2820001

[43] Morgan Vigil, Matthew Rantanen, and Elizabeth Belding. 2015. A First Look at Tribal Web Traffic. In *Proceedings of the 24th International Conference on World Wide Web* (Florence, Italy). International World Wide Web Conferences Steering Committee, Republic and Canton of Geneva, CHE, 1155–1165.

[44] Morgan Vigil-Hayes, Md Nazmul Hossain, Alexander K Elliott, Elizabeth M. Belding, and Ellen Zegura. 2022. LoRaX: Repurposing LoRa as a Low Data Rate Messaging System to Extend Internet Boundaries. In *ACM SIGCAS/SIGCHI Conference on Computing and Sustainable Societies (COMPASS)* (Seattle, WA, USA) *(COMPASS '22)*. Association for Computing Machinery, New York, USA, 195–213. https://doi.org/10.1145/3530190.3534807

[45] Susan P. Wyche, Thomas N. Smyth, Marshini Chetty, Paul M. Aoki, and Rebecca E. Grinter. 2010. Deliberate Interactions: Characterizing Technology Use in Nairobi, Kenya. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. Association for Computing Machinery, New York, USA, 2593–2602. https://doi.org/10.1145/1753326.1753719