A Mixed-Methods Study of Mobile Users' Data Usage Practices in South Africa

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ABSTRACT
With a shift towards usage-based billing, the questions of how data costs affect mobile Internet use and how users manage mobile data arise. In this paper, we describe a mixed-methods study of mobile phone users' data usage practices in South Africa, a country where usage-based billing is prevalent and where data costs are high, to answer these questions. We do so using a large scale survey, in-depth interviews, and logs of actual data usage over time. Our findings suggest that unlike in more developed settings, when data is limited or expensive, mobile Internet users are extremely cost-conscious, and employ various strategies to optimize mobile data usage such as actively disconnecting from the mobile Internet to save data. Based on these findings, we suggest how the Ubicomp and related research communities can better support users that need to carefully manage their data to optimize costs.

Author Keywords
Mobile data; Mobile data tracking; Mobile data costs.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Users are increasingly faced with managing the data usage of data intensive applications [19]. In fact, mobile data usage is predicted to increase nearly tenfold by 2019 owing to an explosion in mobile phone uptake and a surge in the number of mobile Internet users [13]. Although much ubiquitous computing research to date has focused on studying, collecting data, and designing for mobile use, many mobile applications have operated under the assumptions of a constantly available Internet connection with unlimited data [30, 31]. However, a continuing shift away from flat-rate priced unlimited data packages towards usage-based billing on wireless networks where consumers are charged based on how much data they consume [43]—has raised these questions: how do data costs affect mobile Internet usage?; what tools do users employ to monitor and track mobile data usage?; and what are the resulting implications for the design of mobile applications and mobile data monitoring tools?

In this paper, we answer these questions through a mixed-methods study of South African mobile phone users using a large-scale survey of 339 users, in-depth interviews with 43 users, and by collecting almost two years of data usage logs on 121 mobile phones. We chose South Africa, because it is a resource-constrained country where data costs are significantly higher than more developed settings [28, 8]. For instance, like much of Sub-Saharan Africa (SSA), most mobile users in this country are on prepaid plans, and mobile costs comprise a significant portion of monthly income [23]. As such, the effects of cost on mobile data usage in this context are more apparent than in similar settings.

We have four main findings. First, we confirm that mobile data is valued by all users, regardless of income levels, similar to other studies in resource-constrained settings [35, 27]. Second, unlike home network users [10], mobile users in South Africa are fairly aware of how online activities consume data but they still do not understand how to best manage all the data consumers on their phones such as "invisible" built-in operating system processes. Third, users have developed various strategies to optimize data and data costs, including disconnecting themselves regularly from the mobile Internet; a concern that appears less prevalent in developed settings [31]. Fourth, users have set desires to improve mobile data management such as predicting data costs before engaging in an online activity. Our findings suggest that the Ubicomp and related research communities need to better accommodate users who actively disconnect from the mobile Internet to save data. Additionally, our study suggests that mobile users need more transparency about data usage and flexibility in terms of what counts towards data usage, and that developers need improved support to design data slim mobile applications for these settings.

Our contributions are twofold: we provide empirical evidence of how costs affect mobile data usage habits in a resource-constrained setting using a large scale study of existing practices and recommendations for the Ubicomp community to help create mobile applications that accommodate those who need to use data sparingly.

BACKGROUND, RELATED WORK, AND EXISTING TOOLS

Mobile Data Pricing and Pricing Transparency
Despite the Ubicomp community's continued interest in mobile devices [30], there has been little focus on how mobile

UbiComp '15, September 7–11, 2015, Osaka, Japan.

http://dx.doi.org/10.1145/2750858.2804292

Internet users consume data. Yet, billing structures around the world for mobile data are changing [32]. According to Odlyzko et al. [34], unlimited plans are no longer the norm and users are now often faced with a data cap or limit on how much they can upload/download for the month. These authors also note that even unlimited plans have a fair usage policy which means that a user's connection can still be throttled once they have exceeded a predefined data limit. In developing countries such as Ghana where data is extremely expensive, this means that budgeting costs and optimizing data is paramount for users [35].

There have been several studies geared at helping users manage mobile Internet data costs by creating user-facing tools and testing these in experimental settings. In Ghana, Sambasivan et al. [40] created and deployed "SmartBrowse", a real-time mobile data cost monitoring tool for a mobile browser. This tool allowed users to view the costs of Google search results in advance of clicking through the results as well as a data balance bar to help users make informed decisions about spending data to view particular pages. In a study of recruited volunteers given instrumented phones over several weeks, they found users increased their total web page views while simultaneously cutting down on data used. In another set of experimental studies, Sen et al. [42, 26, 29] studied whether "smart data pricing"—the notion of pricing data based on time of the day—could motivate users to shift their online activities both on broadband and mobile networks, with less focus on qualitative measures. While these studies go a long way in examining how to provide data cost transparency to users, they did not study how users currently manage data costs in a non-experimental setting. Our study fills this gap to better inform the design of mobile data management tools.

Smartphone and Mobile Traffic Usage Patterns

Another vein of work focuses on smartphone use, smartphone application behaviors [47], and mobile traffic [22], either by studying devices in the laboratory, or in settings where volunteers are recruited and given instrumented phones [21], or where smartphone users are asked to download a logging application [41]. For example, Rahmati et al. [36] studied mobile application installation patterns and web traffic by recruiting college students from different socio-economic backgrounds to use researcher-provided iPhones for several months. Although these studies shed some light on the data usage habits of users and applications, they do not focus on how users manage mobile data costs or their data usage specifically and most focus on users in developed settings. Most recently, Lord et al. [31] studied 13 iPhone and iPad users using a mixed-methods approach to better understand users' data demands to improve energy savings. This study was conducted over 2 weeks in Europe and they found that users have come to depend on a working data connection to help fill time and fulfill data needs. Our study complements this work by providing large scale evidence of how users manage mobile data and costs and device usage traces for a longer period across a variety of mobile phones in a resource-constrained setting. In addition to collecting usage logs, we focus on how users deal with limited data and high data costs as opposed to making mobile devices more sustainable.

Mobile Data Usage and Costs in South Africa

In South Africa, few studies examine how mobile users manage data costs. In a related area, some researchers studied how household users' deal with fixed line data caps [10] and created a tool for Internet data management but this focused on the home setting only [11]. Other studies have indirectly touched on mobile data costs while studying mobile phone use more generally. For example, Donner et al. [15] observed that managing data expenses was one of the primary concerns for most novice Internet users wanting to get online for the first time. In another study of how low-income Internet users use public access venues (PAV's) such as libraries and Internet cafes, researchers noted that mobile users would often wait in long queues at these venues to access the Internet for free rather than spend money on mobile data [16]. While these studies suggest that the high cost of data may affect mobile data usage, none of them specifically focus on understanding the extent of this effect or what tools these users require to help them better manage data costs—the focus of our work.

Mobile Data Management Tools

Mobile data management is a difficult task because of varied data pricing plans and non-transparent accounting for data consumption which differs amongst mobile service providers and countries [38, 27, 17]. For example, users often have difficulties tracking and managing prepaid calls, mobile data and costs [39]. There are existing mobile data management tools to help users manage mobile data but their efficacy and how users employ these tools remains largely unknown. For example, Android [24] has built-in a data usage monitor to view the breakdown of data usage for each application including background and foreground data usage. This application also allows a user to selectively toggle every installed application's access to mobile data. Apple's iOS also offers a way to track and control cellular data on an application basis [4]. However, in both cases, these settings are not always intuitively placed in the menus, making them hard for users to find. Additionally, both these native applications do not measure data usage by a users' billing cycle or prepaid data bundle, placing the onus on the user to set time periods and track data costs. Finally, although a lot of control is provided, it is unclear how much users understand about how to optimize their data usage in the first place—one of the questions we answer with our study.

A few third party data management applications such as Onavo [2] and My Data Manager [1] partially overcome these issues. These applications allow users to input their monthly billing cycle information to gain greater insights into usage but require users to be familiar with how their data plan is billed. This process can be especially difficult for users on prepaid plans where there is no notion of a monthly billing cycle. Even for users on contract plans, if data is billed at different rates depending on whether a usage cap has been exceeded or not, the information may not be accurate. In some cases, these applications also make it necessary for a

user to sacrifice privacy concerns to optimize data usage. For example, Onavo's Extend application optimizes data usage but requires the user to route all their data through Onavo's own Virtual Private Network (VPN). To sum up, it is unclear how well existing mobile data tracking tools allow a user to manage mobile data. We aim to answer this question with our work to better inform the design of these tools.

METHOD AND PARTICIPANTS

Research context

At the time of this study, the major cellular service providers in South Africa were Cell C, MTN, Telkom/8ta, and Vodacom. These carriers offered two types of mobile plans: contract and prepaid. Prepaid plans or "pay-as-you-go" plans require users to purchase "airtime" and phone credit in advance. Airtime provides access to the cellular network to receive calls and texts for a certain period of time and/or connect to the Internet. Phone credit in ZAR, the South African currency, allows users to make calls and text and/or can be converted to "data credit" at a high cost. For cheaper access to mobile data, users can buy "data bundles"—packages that provide a fixed amount of mobile data for a limited period of time, oftentimes a month. If users on prepaid plans do not purchase a data bundle or exhaust an existing bundle, their airtime is automatically converted to mobile data at a significantly higher billing rate than using a data bundle when they use the Internet.

Contract plans usually include a fixed amount of airtime and mobile data, and require a monthly payment for services based on usage. Like prepaid users, contract users pay a more expensive "out-of-bundle" rate for data once the mobile data cap exhausts. In addition to these plans, most providers offer "power" and "promotional" bundles to supplement existing data plans. These bundles must be used in a short time frame: the former are advertised on certain occasions or times of the year and last typically a day, while the latter last for typically an hour and are often promoted as an inexpensive means to watch videos, listen to music, or connect to social media. The ability to mix and match data plans and different data billing rates complicates the process of determining data costs.

Mobile data can be purchased at most retail stores, via automatic bank teller machines, and on the Internet. Users typically top up data when they run out of airtime, data credit, or both. Data bundles vary in increments from as low as 5 MB to 25 GB for larger bundles [45]. Data prices range between USD 0.002-0.016 per MB for large data bundles to almost ten times that cost for bundles under 500 MB [27]. Thus, the most cost effective rates benefit top-end consumers who can afford large one-time payments for bigger data bundles.

Study Overview

We conducted a mixed-methods study comprising three parts: a large-scale survey, in-depth follow-up interviews, and tracking actual data usage on mobile phones. The timeline and participants for each phase is shown in Table 1.

Study method	Number of users	Time period
Survey	339	Jun–Jul 2014
Interviews	43	Jun–Aug 2014
MySpeedTest	121	Nov 2012–June 2015

Table 1. Summary of study data collected and time frames.

Part 1: Survey

In part one, we developed and administered an online survey to users living in South Africa to determine current mobile data usage and cost management practices in June-July 2014. We collected basic demographic information and asked about current Internet practices. The survey also focused on themes adapted from a similar study in the home [10] such as how and where users consume mobile data, mobile data spending habits, user perceptions of what consumes mobile data, tools employed to track data usage, and feelings about mobile data.

We advertised this survey, which took no longer than 20 minutes to complete, on one of the most popular web forums in the country, through social media such as Facebook and Twitter, our institutional website, and local contact networks in the country. As such, our recruiting pool was skewed towards those who already had access to mobile Internet. To ensure that we had representative users across income and education levels, we also recruited 15 participants from three low-income areas and administered the survey in-person to them with the help of a field assistant. All survey participants were entered into a draw for five USD 50 gift cards as compensation for participation.

In total, we received 339 complete responses and analyzed these using standard descriptive statistical methods. Where possible, we analyzed the results across medium to high (N= 165) and low-income (N=119) users to compare and contrast the behaviors observed. We used ZAR 100,000 or USD 8,583 as the income demarcation level between medium to high and low-income users based on the income classification used in the most recent country census [7]. We chose to exclude those respondents who withheld their income (N=55) when analyzing across income levels and refer to the division as "low" and "high" income in the remainder of the paper.

Part 2: Interviews

In part two, we conducted 43 semi-structured interviews with survey respondents and covered the same themes as the survey but in greater depth. These interviews lasted between 30 minutes to 1 hour and were conducted over Skype, in-person, or on the telephone. In some cases, interviews were conducted in Xhosa, a local language, and later translated to English. We compensated all interviewees with either USD 15 gift cards or airtime vouchers for participating.

All interviews were audio-taped and transcribed. We analyzed the transcripts and our field notes, coding them using inductive thematic coding [14]. All resulting themes were discussed with the research team before we reached consensus on final trends to triangulate with the other data.

Part 3: Tracking Data Usage

In part three, we tracked mobile users' data usage over time by asking them to download and install an open source

		Low income users N = 119	High income users N = 165	Overall N = 339
Age	<18–24	33.7%	12.7%	24.2%
	25–34	36.1%	46.0%	**40.7%**
	>35–54+	30.2%	40.7%	34.8%
	Withheld	0.0%	0.6%	0.3%
Gender	Male	77.3%	86.1%	**81.1%**
	Female	21.8%	13.9%	18.6%
	Other	0.9%	0.0%	0.3%
Education	School	**51.3%**	28.5%	38.1%
	Undergrad	20.2%	29.1%	26.0%
	Graduate	6.7%	32.1%	20.9%
	Other	21.8%	10.3%	15.0%
@home	Broadband	42.0%	**64.8%**	56.0%
	Mobile	**58.0%**	35.2%	43.7%
	No Internet	0.00%	0.00%	0.3%
Monthly median expenditure on mobile data (USD)		13.5	16.5	13.5

Table 2. Demographic information of the survey users (a subset of which were interviewees) including the type of Internet connection participants have at home, and their median expenditure on mobile data per month.

Android mobile logging application on their phones. The application, MySpeedTest, developed by our collaborators and described in [12], collects information about mobile Internet performance and data usage. MySpeedTest performs both "active" and "passive" network measurements. Users have to initiate active measurements such as speed tests where data is transmitted to and from the phone. Passive measurements run in the background when the phone is on and connected to the Internet. While active measurements evaluate network performance, passive measurements monitor each mobile application's data usage, along with the type of network—mobile or wireless—used to connect to the Internet. MySpeedTest also collects basic demographics, such as location, network provider name, network type, and phone manufacturer.

We began recruiting MySpeedTest users in late 2012 and continued to actively recruit users in 2013 and 2014. Users were recruited via social media, contact networks, mailing lists, our own promotional websites, and via the Google Play Store, and offered incentives for participation. The first incentive was a draw to win a mobile phone in 2013 for using MySpeedTest for at least one month. In 2014, users were entered into a draw for three 2 TB hard disks for using the application for at least a month.

For this paper, we analyzed MySpeedTest passive measurements from November 2012-June 2015. During the study, 276 South African users installed MySpeedTest on their phones. Since users could un-install MySpeedTest or turn their phones off/disconnect from the Internet, the number of measurements varied for each user. To compensate for users with insufficient data, we filtered out those with less than 30 days of overall usage, yielding 121 users. In terms of measurements, the median number of days MySpeedTest was used per user was 91 days, and the median number of mobile applications—including user-installed, pre-installed, and built-in applications—recorded per user was 104.

In our analysis, we calculated the applications that used the most data. To do so, we first calculated the median of median daily usage for each application across all users. We then filtered out those applications that were used by less than half of the users (N=61) to ensure "popularity" and then ranked the applications by data consumed on either the mobile or Wi-Fi connection. We refer to these applications as the top 10 data consuming applications on mobile or Wi-Fi in the remainder of the paper. MySpeedTest does not measure whether an application runs in the foreground or background or the time a user spends using each application. Therefore, we cannot report on how the data volume correlates with time. Note that we specify both the application and the package names to keep the origin of the applications clear.

Data Triangulation

To triangulate our data, we first examined broad themes emerging from our survey responses. We then referred to the interviews for in-depth information on these themes and finally, we used the MySpeedTest data to confirm whether the actual data usage patterns matched these themes. In the paper, we discuss the final results grounded in all three data sources, referring to each where appropriate.

Participant Demographics

Table 2 summarizes the demographics of the survey respondents, a subset of which comprised the interviewees split across low (N=25), high (N=12), and unknown (N=6) income levels. The majority of our participants were in the 25-34 years range. Most low-income respondents had completed high school. The high-income respondents, on the other hand, were split fairly evenly between having completed high school, undergraduate and graduate degrees and hence, were more educated. Respondents were primarily male and were concentrated in the major metropolitan areas of the country such as the cities of Cape Town, Johannesburg, Durban, and Pretoria. Given that we recruited the majority of our participants through an existing web forum, our sample was skewed towards more educated existing mobile Internet users. Table 3 summarizes the network and device information for the 121 MySpeedTest users.

FINDINGS

Similar to other studies [35, 27], our findings show that our participants, particularly the low-income ones, valued mobile data but managing data usage was non-trivial. Second, we found that, unlike home network users [10], while mobile users have a rudimentary idea about what consumes data, they lack an in-depth understanding about "invisible" data users or processes that consume data in the background. Third,

		Number of users N = 121
Network Provider	8.ta	6
	Cell C	21
	MTN	30
	Vodacom	57
	Telkom	2
	Unknown	5
Connection Type	GSM	117
	Unknown	4
Phone Manufacturer	HTC	9
	LGE	6
	Sony	8
	Samsung	98

Table 3. Demographic information of the MySpeedTest users displaying the network provider, type of connection, and phone manufacturer.

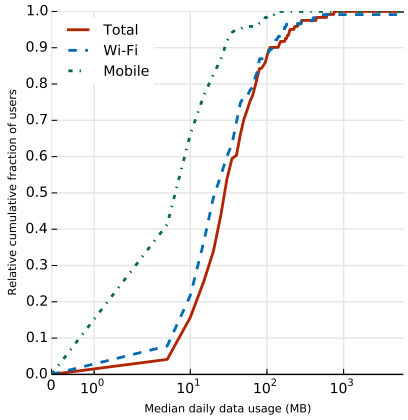

Figure 1. Median daily data usage across all users including breakdown of usage on mobile versus Wi-Fi connections.

users employ a variety of strategies to optimize data usage and minimize costs—a concern that appears less prevalent in developed settings [31]. Many of these strategies are cumbersome and actively involve disconnecting from the mobile Internet. Finally, users have set desires for improving mobile data management such as desiring real-time tracking, predictive tracking, and more control over mobile data usage.

Mobile Data Uses, Costs, and Value

The largest mobile providers in the country dominated our survey and interview sample with participants using Vodacom (34.0%), MTN (20.7%) and Telkom (17.3%). Our MySpeedTest users also predominantly used these providers including Cell C, and Samsung was the most popular mobile vendor amongst these users. On average, our participants owned 3 mobile devices—phones, laptops, and tablets— that regularly connected to the Internet and used mobile data on 2 of these devices. High-income participants owned more advanced iOS/Android powered devices while low-income participants tended to own basic feature phones, the latter of which were less costly overall. About 90% of all participants used the mobile Internet every day at home for social media and messaging, or the workplace; 67.9% spent more money on mobile data than phone calls and text messages; and 66.0% typically used the Internet at home.

There was a slight variation in the median spending per month on mobile data, as summarized in Table 2, with high-income participants spending a median monthly amount of USD 16.5 and low-income participants spending a lower median monthly amount of USD 13.5. Given that over two-thirds of users spent more money on mobile data than calls or text and all users spent a significant amount on mobile data per month, this suggests that mobile data was as important to all users regardless of cost—a theme we noted in the interviews. Our MySpeedTest data similarly shows that users made use of mobile data regularly. As seen in the graph in Figure 1, 90% of our MySpeedTest users had a median data usage of less than 100 MB per day, with the last 10% of users being heavy users. Only 15% of users had a median daily data usage of less than 10 MB per day.

As seen in Table 2, about two-thirds of the high-income participants in our survey reported using broadband at home as their primary connection, while more than half the low-income participants used mobile data as their primary Internet connection. Also, while high-income participants often had access to both Wi-Fi and mobile data, many low-income participants used only the latter. Previous studies such as [12] describe the high costs of the monopolized broadband market and installation hassles such as taking longer to install, requiring more expensive equipment such as modems and telephone lines, and being contract bound as the reasons users go mobile only. Figure 1 shows that 90% of MySpeedTest users had a median data usage of nearly twice as much on Wi-Fi as opposed to mobile per day. This suggests that users may prefer using a Wi-Fi connection when available—a theme also reflected in the interview data.

Data Costs

Costs dictated the participants' choice of mobile billing plans. In our interviews, most low-income participants and interestingly, even a few high-income ones, told us they preferred prepaid plans over contracts. Participants explained that prepaid billing gives them more control over call, text, and data expenditures. For example, low-income participant P22 told us: *"I can't go on contract because I'm not sure that I'd have money at the end of the month. I prefer prepaid [because] I know I can afford it."* These prepaid users also told us how they liked using the Internet based on need rather than having a contract data plan which comes with a danger of exceeding costs and data caps as well as incurring out-of-bundle charges. Participant P23 expressed this view as: *"On prepaid, I get to decide how much money I can spend on data and I get to control as well my airtime. What I do is I buy 110 megs of data. From that 110, I get to see how much I spend in buying data, whether it's every week or every*

day. I get to decide whether I want 100 megabyte for ZAR 29, or I want 30 megabytes for ZAR 12—I get to decide!" The popularity of prepaid plans amongst low-income participants reinforces the notion that managing data and costs is very challenging for mobile Internet users.

Mobile Data and the Importance of Staying Connected

In our survey, we asked the participants to rank food/water, education, entertainment, health, living, clothing and mobile data expenses in terms of importance. Unlike high-income users, low-income participants ranked mobile data higher than all other expenses aside from food/water much like in similar studies [27]. From the interviews, we observed that for these participants, not only did mobile data provide access to the Internet, it also appeared to be an essential part of happiness. They told us of the joy it brought to their lives—either in terms of job opportunities or staying connected to one another. Many also expressed that they felt disconnected and depressed when they could no longer afford it or overshot their usage inadvertently. For this reason, these participants cut down on all other necessities, e.g., smoking or movies (P5), to balance out their mobile data expenditure. Participant P21 for instance, said: *"I cut down on my hair [products]. I just wash my hair once every 2 weeks to save money for data. I was in the Free State and my phone was off and I felt dead inside."* In other cases, participants went to extremes as summarized by P42: *"Yes, the money I use to buy data is the money I save for food and snacks."*

In fact, P41's quote typifies the type of feelings participants spoke of: *"Sometimes I go on the Internet more than I intended to. And when I check my data, I would have, say only 3MB, and I can't do anything with that and I don't have airtime. Sometimes I get angry. I don't understand what happened."* Our high-income participants did not express the same sentiments towards mobile data or talk about sacrificing other needs for mobile data.

In summary, participants varied on how and where they used the mobile Internet and how they purchased mobile data based on how they wanted to manage their expenses, with low-income participants preferring more control over spending overall. Low-income participants also felt a need to prioritize mobile data over other goods—basic or luxury—to stay connected to their personal and professional networks.

User Perceptions vs Actual Mobile Data Consumption

Our participants were knowledgeable about certain online activities that consume mobile data but still found aspects of data usage confusing. Their perceptions mostly matched what we observed in actual data usage trends.

Multimedia Applications

We asked survey participants about which applications consumed the most data on their phones. Unlike in home networks [10], participants had a fair idea of what applications used up a lot of data: 84% of them reported that watching a video for 10 minutes would consume more mobile data than using a social networking website or reading a text article for the same amount of time. In the interviews, P14 explained further: *"I would say I do browse on the Internet, and I know that does not use a lot of data. But when it comes to streaming of things from YouTube etc, I know that takes a lot of data."* Participants appeared to gain this knowledge by regularly checking their data balances.

In fact, only 57.4% of the survey respondents reported tracking mobile data in some way but tracking appeared more prevalent in our interview data. In the interviews, we learned that the participants constantly checked their data balances when using popular applications such as Facebook, Instagram, and YouTube to stay within the limits of their data quota. For instance, participant P10, like many others, dialed carrier specific numbers called Unstructured Supplementary Service Data (USSD) codes to view data balances: *"I check my airtime balance, and I will see. I know Facebook and Instagram takes most of the data. So I will use it on that, then I'll check again, then I use and use, and then I will put my data off."* In another example, P31 told us: *"I check my balance before I go onto the Internet and once I come off then I check my balance again, so that's how I'm able to track how much I'm using exactly."* This pre and post-activity balance checking helped participants correlate the online activities they were engaged in with how much data the applications used and ultimately, helped them to keep data costs low.

When we looked at the range of median daily data usage for applications in our MySpeedTest data, we found that users vary considerably in terms of their data consumption practices. In terms of multimedia applications, the expected high data users such as YouTube and Skype appeared only in the top 30 data consuming applications. Interestingly, on both mobile and Wi-Fi, three of the top 10 data consumers are social media applications such as "Facebook" and "Twitter" (see Tables 4 and 5), indicating users' preference for communication applications. We discuss other applications that consume a lot of data next.

Background Applications and Services

Our participants told us that there were still aspects of data usage that were not as easy to see or estimate. For instance, a few participants complained that mobile applications running in the background were often a source of confusion because their data usage was not readily visible to the user. Participant P29 explained further: *"I don't understand how Facebook Messenger works for instance. I mean I think it's off. There are times when I initially started using it and I would think it was off because it's not anywhere here right. And then all of a sudden you just notice the chat comes on. It probably doesn't use a lot of data but I'm just using it as an example."*

This "invisible" data usage, i.e. use that is only sometimes perceptible to the users, is reflected in the MySpeedTest data in Tables 4 and 5, which show the top 10 data consuming applications on mobile and Wi-Fi. While we did not collect information on background/foreground use, we do know that many of the applications appearing in the table run as services. For instance, "com.android" indicates packages specific to the Android OS. Table 4 shows the top data users on mobile include services related to synchronization, the Google Play store, and location. Similarly on Wi-Fi, Table 5 shows the major data consumers are services related

Application Name	Package Name	No. of Users	Median Daily Usage (MB)	Network Type	
				Median Daily Mobile Usage (MB)	Median Daily Wi-Fi Usage (MB)
Facebook	com.facebook.katana	98	1.69	0.52	0.94
Administrator ctas.	com.google.android.gsf.login	102	0.29	0.15	0.17
Google Contacts Sync	com.google.android.syncadapters.contacts	113	0.29	0.15	0.14
Google Play Services	com.google.android.gms	114	0.30	0.15	0.15
Network Location	com.google.android.location	101	0.29	0.15	0.16
Twitter	com.twitter.android	70	0.44	0.14	0.22
Google Bookmarks Sync	com.google.android.syncadapters.bookmarks	80	0.27	0.14	0.15
Google Services Fram	com.google.android.gsf	109	0.29	0.13	0.13
Google Play Store	com.android.vending	119	0.24	0.09	0.19
WhatsApp	com.whatsapp	108	0.15	0.06	0.07

Table 4. MySpeedTest Users' Top 10 Data Consuming Applications Ordered By Mobile Usage.

to downloads including the Digital Rights Manager (DRM) package. These tables suggest users do not always have direct control over data usage in that they may not realize that their mobile activities also incur data costs from other services in the operating system (e.g. synchronization services).

Overall, across network types, most packages are predominantly used on Wi-Fi rather than mobile networks. In our interviews we learned that Wi-Fi is preferred when it is available because of the expense of mobile data. To sum up, participants were still confused about what contributes to the data balance on the phone, particularly since not all use is "visible" to the user. This makes it difficult for users to control all their data usage and costs.

Strategies for Optimizing Data Usage and Costs

Our participants identified how certain activities use up mobile data fairly quickly. They adjusted their behaviors to keep data usage to a minimum to optimize costs and prolong their access to the mobile Internet. We describe the various strategies participants told us they used below.

Switching-off the Data Connection and Postponing Use

The most widely used mechanism to reduce data usage was to switch off the data connection—and hence cut off Internet access to mobile applications—when not in use such as when connected to Wi-Fi or when participants did not want to explicitly be online. Participants generally spoke of using the mobile data connection deliberately—similar to behaviors on fixed lines in other resource-constrained settings [46]. They switched the connection on, performed an online activity, and then switched the connection off once the activity was complete in order to save on mobile data. We also learned that participants switched off the mobile data at night or when they were away from their phones. For instance, participant P10 explained: *"If I keep my data connection on, it's gonna run continuously because I'm getting messages, posts and likes. It must be off in order for my megabytes to last. I put it on when I'm chatting, and when I'm busy I put it off."*

Other users merely switched their phones into "flight mode"—which blocks all networked connections to the device and is usually used during air travel—to ward off unwanted data usage. This is exemplified by a quote from P6: *"I used to sort of put it on airplane mode a lot when I was in meetings and disabled data unless I wanted to go online."* Across all users, it was evident that mobile data was not always-on and considered a precious resource to be conserved for times of need only.

The majority of participants also told us that they deferred performing data intensive tasks, such as watching videos and software updates, to times when they would have access to a Wi-Fi connection. While many high-income participants reported having access to Wi-Fi at work or at home, low-income participants sought wireless Internet access either at libraries or other public access venues where Wi-Fi was free as expressed by P1: *"In Mitchell's Plain the only free available Wi-Fi is McDonald's, and I really go."* In another example, P11 told us: *"Occasionally I will see something needs updating and I will rather do it if I am on a Wi-Fi connection somewhere where there is unlimited data."*

This trend was reflected in the MySpeedTest data. As shown in Figure 1, 90% of users consumed twice as much data on Wi-Fi than on a mobile connection on a daily basis. In addition, many of top 10 mobile data consuming applications across users shown in Table 4, including Facebook, Twitter, and the Google Play Store, are used more on Wi-Fi. This could either be because users changed settings for these applications to use Wi-Fi only or consciously used Wi-Fi over mobile data. In fact, only background services such as Google Play services which supports the Google Play Store [25], were used about the same on both Wi-Fi and mobile connections (although it is unclear if these are user-initiated).

Avoiding Data Intensive Applications and Changing Settings

We observed that all participants were reluctant to access and engage in what they perceived as data intensive activities

Application Name	Package Name	No. of Users	Median Daily Usage (MB)	Network Type	
				Median Daily Mobile Usage (MB)	Median Daily Wi-Fi Usage (MB)
com.sec.android.prov	com.sec.android.providers.downloads	65	3.09	0.00	2.53
Download Manager	com.android.providers.downloads	115	2.71	0.00	2.09
Almacenamiento de co	com.android.providers.drm	102	2.28	0.00	1.62
Media Storage	com.android.providers.media	110	1.90	0.00	1.11
Downloads	com.android.providers.downloads.ui	103	0.99	0.00	1.04
Facebook	com.facebook.katana	98	1.69	0.52	0.94
Twitter	com.twitter.android	70	0.44	0.14	0.22
Google Play Store	com.android.vending	119	0.24	0.09	0.19
Administrator ctas.	com.google.gsf.login	102	0.29	0.15	0.17
Google+	com.google.android.apps.plus	83	0.24	0.06	0.16

Table 5. MySpeedTest Users' Top 10 Data Consuming Applications Ordered By Wi-Fi Usage.

such as watching videos or downloading large files unless absolutely necessary. In fact, participants approached new applications and websites with caution because of the uncertainty around how much data these activities could consume. P18 summarized the concern expressed by our participants: *"I just struggle sometimes. Maybe if I have enough data to do a certain upgrade if I now need to have it done or if I wanted to watch something. I'm so scared because I wouldn't know how much data it will take so it could take all my data. So I think that's the frustrating part."*

Participants also learned about what consumed data from running out of data fairly quickly because of engaging in a certain activity such as watching a video and coupling this with checking their data balances. Based on this knowledge, they often closed these applications and killed processes in an attempt to reduce data usage. For example, P12 reported: *"To cut costs on mobile data, I normally just turn off applications on my phone that require a data connection."*

A few participants explicitly pinpointed software updates for applications and operating system as consuming a lot of mobile data. These participants also told us that consequently they disabled automatic updates to save on mobile data costs. Participant P19 explained: *"If you do not do your settings correctly, your android phone will update automatically, your tablet will update automatically and I have noticed that my data sometimes drops."* This presents a larger security concern than for those users who told us they defer updates to times when they have a Wi-Fi connection.

Other participants told us that they changed their applications' synchronization settings with the cloud to conserve the number of non-essential data exchanges. Participant P6 summarized this strategy as: *"Yes, I think I changed [sync] settings on as many of them as I could figure out at the time. But a lot of them I think it's just sort of automatic. Because it's Apple, it doesn't really assume that you're in a third world context where things are expensive."* In this case, participants were knowledgeable enough to know where to alter these settings but still had to do this on a per application basis.

Using Special Data Bundles

Participants told us that they purchased power or promotional bundles to optimize their data usage. While most participants appreciated the monetary value of these bundles, the fact that they lasted only a few hours was frustrating because this was often not enough time to consume the entire data amount. This sentiment is summarized by P22: *"Sometimes the added bundles are a bonus but can expire before you actually use it."* Therefore, for our respondents, this was a short-lived and non-optimal strategy.

Overall, our participants demonstrated considerable skill in managing their data connection and employed a variety of different strategies to help them manage their data. They either avoided what they perceived as data intensive activities or actively disconnected themselves or the applications from the mobile Internet to conserve data.

Existing and Future Mobile Data Management Tools

Although most participants used USSD codes to check their balances, they found this approach inconvenient, cumbersome, and time-consuming. For example, P23 explained the complexity of the accompanying mental calculations required: *"I calculate if I see that I have 34.5 megabytes left. Then I'll write it down somewhere. And then when I go and check later on, after some time, I'll check it. And then I'll use the calculations to see how much did I use up."* However, this was still the most popular mechanism to determine how much data each online activity consumed.

Only a few participants mentioned using their service provider's data usage alerts and notifications to set up reminders at regular intervals to avoid overshooting their mobile data limit. Participant P14 said: *"I have got a little notification that can send me notifications that say, you have reached your 75% limit, 50%, 25%, so I always know where*

I am, and I sort of plan it so I do not over use and get to the point where I run out of data totally." Even those that used these notifications felt they often contained discrepancies. Participant P27 said: *"If they give you a warning, it is not actually an accurate warning. Because you need to phone the call centre every time to find out to get an accurate figure. And to determine if you are in or out of bundle. Also, when you do get a SMS, and you phone them and then they say, please ignore that SMS."* Thus, carrier notifications were deemed helpful in theory but less so in practice because users perceived them as non real-time indicators of when data would run out or be billed at higher rates.

Where carriers offered data tracking applications, they were still not ideal. For example, the few participants that used these told us there was no easy way for them to track their usage without constantly visiting these applications and this proved to be a barrier for use. For instance, P4 summarized this issue: *"Vodacom has an app that I have got on my phone. At times, I find that it is me that actually lacks going onto it. I do normally go on there about twice a month, just to go and check, or track my usage, and my balances."* Only a few participants explicitly mentioned existing data management tools such as the Android built-in data usage monitor, suggesting the use of these tools is limited. Overall, our data highlighted the drawbacks of existing tools and offered directions for improvement.

Real-time, Predictive Tracking, and Improved Controls

When asked to speculate on future data management tools, participants converged on three major themes. Many suggested having a real-time data tracking tool capable of reporting usage not only in terms of data but also in monetary terms with insights into particular applications' behavior. They believed this would better help them optimize their experience and expenditure. For instance, participant P19 explained: *"I'd probably love it if I could get a better sense of how much I was spending on a particular app. For instance, I have BBC app. And I want to be able to see how much money I am spending every minute, so that I know when to switch it off."* Participants also felt that they could better manage data if they had the ability to predict the amount of data a website or application required in advance of visiting or using that service. This predictive information would then help them make an informed decision about whether or not to go ahead with their planned online activities.

Other participants desired the ability to limit each application's, or each device's data quota because they felt this additional level of control would help them stay within their data budgets. The following quote from P29 summarizes this viewpoint: *"I want to be able to specify how much data I want a particular app to use in a particular month right. So for instance, I want my WhatsApp application to be dedicated 20 MB worth of data every month, whether I like it or not. I know I'll probably use less, but I know that it's an important app."*. What is surprising is that many participants were unaware that their phones—in most cases and Android or iPhone devices—could already offer some of these capabilities. To sum up, across income levels, participants suggested that real time data tracking, predictive information about potential data use before engaging in an activity, and improved control over data usage would help them to efficiently optimize usage and costs.

DISCUSSION

Although our study took place in South Africa, usage-based billing is becoming more common in many countries around the world including the United States [44]. In addition, shared data plans amongst multiple people and devices are growing in popularity. Thus, it is important for the Ubicomp community to determine how to help users manage mobile data and costs since this affects how and when users get online and use mobile applications.

Limited Data Leads to Disconnection

Our study suggests that that when data is limited or data costs are high, users frequently disconnect from the mobile Internet or disrupt connections to their applications to avoid using mobile data unnecessarily and keep costs low. Participants also self-regulated their behaviors such as avoiding websites and activities they perceived as high data consumers, switching to Wi-Fi when available, and switching the data connection off when not explicitly engaged in online activities. Overall, this suggests that rather than having anytime anywhere access to the mobile Internet, our participants interacted with mobile data in a more deliberate, planned and purposeful way—a style noted in other regions where Internet constraints such as limited bandwidth and connectivity are prevalent [46].

For Ubicomp, this means as a community we have to rethink assumptions about how users will engage with our tools and applications and how to explicitly design for and leverage disconnection. For example, recent versions of Facebook automatically played videos embedded in news feeds [18] yet this is not desirable for data conscious users. Similarly, mechanisms to improve mobile performance such as pre-fetching and caching (e.g. of mobile video advertisements [9]) can actually help users to be data frugal and as a community we should invest more resources in work that focuses on limiting unnecessary data transfers. Questions that could be further explored include what are the priorities of users who want to actively disconnect versus trade-offs in performance and how can we better support these priorities?

Improving Mobile Internet Data Management

Our findings highlight opportunities to improve mobile data management. For example, to ameliorate security issues caused by users disabling data heavy software updates, providers could consider "zero-rating" these updates, i.e., not counting the data they consume towards a mobile data limit. Facebook and Google already use a zero-rating approach in various countries to provide users free access to their applications [33]. However, zero-rating is not without disadvantages. In particular, Best [5] raised concerns that such approaches can further disempower users in countries where data is very expensive by providing them only with access to a walled and curated set of Internet services. The question then becomes who decides what is zero-rated or

not? For instance, a recent ruling in Canada [6] prevents mobile providers from zero-rating their own streaming media services on wireless connections to give consumers more freedom of choice in what content they consume rather than be bound by data efficient choices. Another solution may be to provide more deals with free Wi-Fi access so that users can download certain content without relying on mobile data. However, even with such deals, given that many users may not regularly have Wi-Fi access at work, home, or at public access venues, improving users' ability to manage their mobile data usage is important.

Yet, providing great data transparency in terms of real-time and predictive tracking that includes monetary costs is tricky. In particular, including information about data costs depends on having access to how mobile plans are billed by a mobile service provider which varies across providers and in different regions. In addition, since mobile data plans are so convoluted, self-reported data billing rates from user may not be sufficiently accurate for a useful system. For instance, a user may not know immediately when their billing switches from in-bundle to out-of-bundle rates. What is clear is that users need better ways to see and control data users, including often "invisible" applications that come pre-packaged with a phone or operating system. Although there are existing data tracking applications (built into the operating system or third-party), our findings suggest that users are not always aware of these data monitoring and control functions and that these application interfaces can be improved.

For instance, Sambasivan et al.'s Smartbrowse prototype [40]—that helps users to correlate their data usage with their online activities—could be extended beyond the browser as a balance bar that could be overlaid on the top of other applications or hidden at will. The difficulty of tracking data could also be reduced by providing a function to mimic a USSD balance check to help users more easily understand what uses up mobile data. This would allow a user to set a timer when they start using mobile data for an application or activity and then stop it when they are finished to automatically calculate how much data has been used in between, and by which applications.

Aside from greater mobile data usage transparency, the complexity of controlling mobile data use, such as disabling background data usage, on the phone needs to be addressed. For example, instead of making assumptions about a user's data budget, when an application is installed on a mobile phone, users could be asked at that point whether or not the application should use mobile data or Wi-Fi only. The user could also be asked if there are data caps to be aware of and set data limits on the application. This makes it more likely that frequently used applications behave as a user expects with regards to data usage. It is also less overwhelming than having to set controls on a per-app basis at a later stage (recall our MySpeedTest users had a median of 104 applications on their phones).

Finally, instead of focusing solely on the user, the Ubicomp community could create better development tools that allow mobile application developers to test out and identify out how different parts of their applications consume data and which suggest how to optimize these parts of an application. This could help eliminate the problem of background processes consuming large amounts of data unnecessarily more effectively than providing users with more control over these processes directly. For example, in a related vein, Facebook developed an application for their developers called Air Traffic Control (ATC) [20] to allow them to optimize the mobile Facebook application for different network conditions. These tools allow mobile developers to provide versions of their software in "data lite" forms, such as Facebook Lite [37], to help users conserve data. Abowd has suggested improving programming environments for developers is a promising new area of work for Ubicomp [3] - this is a well suited focus to help create applications that have data constraints in mind from the ground up.

Reflecting on a Mixed-Methods Approach

Having traces of actual data usage along with the qualitative data allowed us to derive insights about overall patterns of use and to confirm self-reported findings in a way that would not be possible without the MySpeedTest data. However, this approach requires many more resources than using qualitative measures alone. One of the most difficult issues we experienced was ensuring that our users were incentivized to download and continue using MySpeedTest through the study period. Also, the fact that users often disconnected entirely from the Internet and that they could uninstall MySpeedTest at any point, led to gaps in continuous measurements, complicating aspects of data analysis.

For us, having regular recruiting drives and providing good incentives such as the opportunity to win mobile phones helped us keep users engaged. Ideally, in a study one would use the same users for all three parts (survey, interviews, and logging) and include non-Android users. However, this approach may not scale as easily without proper incentives for continued engagement and given the time commitment involved, the question of how to effectively recruit users to participate in all three parts of the study remains open. Overall, we recommend the three pronged approach to those in the Ubicomp community with the resources to do so or for researchers who have the opportunity to collaborate with others who either generate or have access to such data. Combining the qualitative and logging data is worth the effort to more comprehensively understand mobile Internet use.

CONCLUSION

In this paper, we make two contributions: we provide empirical evidence of mobile Internet users' data usage practices in South Africa and recommendations for the Ubicomp community to better accommodate mobile Internet users who need to optimize data usage and costs. Our findings suggest that the Ubicomp community needs to explore what it means to design for users who actively disconnect from the mobile Internet to save data, how to provide greater transparency to users over mobile data usage, and flexibility in terms of what counts towards data usage. As a community, we can also help designers more easily create data slim mobile applications to accommodate users

who need to be data wary. In the future, we plan to expand this work to explore whether the patterns of use we observed in this resource-constrained setting hold for mobile users in developed settings. We are also currently building a tool to help mobile developers test and refine their applications for resource-constrained settings.

ACKNOWLEDGEMENTS

We thank our participants, MyBroadband, and Nick Feamster, Andrew Kim, and Miseon Park who developed MySpeedTest with funding from NSF CNS-1535796. Our work was funded by a Google Faculty Research grant.

REFERENCES

1. My Data Manager. http://www.mydatamanagerapp.com.
2. Onavo data tracking application. https://www.onavo.com.
3. Abowd, G. D. What Next, Ubicomp?: Celebrating an Intellectual Disappearing Act. UbiComp '12, ACM (New York, NY, USA, 2012), 31–40.
4. Apple. Learn about cellular data settings and usage on your iPhone and iPad (Cellular Model). http://support.apple.com/en-us/HT201299.
5. Best, M. L. The Internet That Facebook Built. *Commun. ACM 57*, 12 (Nov. 2014), 21–23.
6. Brodkin, J. Data caps cant be used to snuff out competition, Canada ruling says. http://arstechnica.com/business/2015/01/data-caps-cant-be-used-to-snuff-out-competition-canada-ruling-says/, 2015.
7. Bureau of Market Research, University of South Africa. Bureau of Market Research: Information Blurb; Personal Income Estimates for South Africa, 2011. http://www.unisa.ac.za/contents/faculties/ems/docs/bmr_info_blurp_407.pdf, 2011.
8. Calandro, E., Gillwald, A., and Rademan, B. SA Broadband Quality Drops But Prices Remain High. ResearchICTAfrica Policy Brief No. 6, 2014. http://www.researchictafrica.net/publications/Research_ICT_Africa_Policy_Briefs/RIA_Policy_Brief_August_2014_No_6_Broadband.pdf.
9. Carpen Amarie, M., Pefkianakis, I., and Lundgren, H. Mobile Video Ad Caching on Smartphones. UbiComp '14, ACM (New York, NY, USA, 2014), 57–61.
10. Chetty, M., Banks, R., Brush, A., Donner, J., and Grinter, R. You're Capped: Understanding the Effects of Bandwidth Caps on Broadband Use in the Home. CHI '12, ACM (New York, NY, USA, 2012), 3021–3030.
11. Chetty, M., Kim, H., Sundaresan, S., Burnett, S., Feamster, N., and Edwards, W. ucap: An Internet Data Management Tool For The Home. To Appear CHI '15, ACM (New York, NY, USA, 2015).
12. Chetty, M., Sundaresan, S., Muckaden, S., Feamster, N., and Calandro, E. Measuring Broadband Performance in South Africa. ACM DEV-4 '13, ACM (New York, NY, USA, 2013), 1:1–1:10.
13. Cisco. Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014–2019. http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf, February 2015.
14. Corbin, J., and Strauss, A. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. SAGE Publications, 2008.
15. Donner, J., Gitau, S., and Marsden, G. Exploring Mobile-only Internet Use: Results of a Training Study in Urban South Africa. *International Journal of Communication 5*, 0 (2011).
16. Donner, J., and Walton, M. Your Phone Has Internet - Why Are You at a Library PC? Re-imagining Public Access in the Mobile Internet Era. In *Human-Computer Interaction INTERACT 2013*, P. Kotz, G. Marsden, G. Lindgaard, J. Wesson, and M. Winckler, Eds., vol. 8117 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, 347–364.
17. Donovan, K., and Donner, J. A note on the availability (and importance) of pre-paid mobile data in Africa. In *"Proceedings of the 2nd International Conference on Mobile Communication Technology for Development"*, Karlstad University Studies (2010), 263–267.
18. Elliott, M. How to disable autoplay for Facebook videos. http://www.cnet.com/how-to/how-to-disable-autoplay-for-facebook-videos, 2014.
19. Ericsson. Ericsson Mobility Report on the Pulse of the Networked Society. http://www.ericsson.com/res/docs/2014/ericsson-mobility-report-november-2014.pdf, November 2014.
20. Facebook, Ericsson, and Qualcomm. A Focus on Efficiency - A white paper from Facebook, Ericsson and Qualcomm. https://fbcdn-dragon-a.akamaihd.net/hphotos-ak-prn1/851575_520797877991079_393255490_n.pdf, 2013.
21. Falaki, H., Lymberopoulos, D., Mahajan, R., Kandula, S., and Estrin, D. A First Look at Traffic on Smartphones. IMC '10, ACM (New York, NY, USA, 2010), 281–287.
22. Falaki, H., Mahajan, R., Kandula, S., Lymberopoulos, D., Govindan, R., and Estrin, D. Diversity in Smartphone Usage. MobiSys '10, ACM (New York, NY, USA, 2010), 179–194.
23. GMSA. The Mobile Economy:Sub-Saharan Africa 2014. http://www.gsmamobileeconomyafrica.com/GSMA_ME_SubSaharanAfrica_Web_Singles.pdf, 2014.
24. Google. Optimize data usage. https://support.google.com/nexus/answer/2819524?hl=en.

25. Google. Google play services. https://play.google.com/store/apps/details?id=com.google.android.gms&hl=en, 2015.
26. Ha, S., Sen, S., Joe-Wong, C., Im, Y., and Chiang, M. TUBE: Time-dependent Pricing for Mobile Data. SIGCOMM '12, ACM (New York, NY, USA, 2012), 247–258.
27. infoDev. Mobile Usage at the Base of the Pyramid in Kenya. World Bank (2012).
28. International Telecommunication Union. Measuring the Information Society Report 2014 . http://www.itu.int/en/ITU-D/Statistics/Documents/publications/mis2014/MIS2014_without_Annex_4.pdf, 2014.
29. Joe-Wong, C., Ha, S., Sen, S., and Chiang, M. Do Mobile Data Plans Affect Usage? Results From A Pricing Trial With ISP Customers. To Appear PAM '15, ACM (New York, NY, USA, 2015).
30. Liu, Y., Goncalves, J., Ferreira, D., Hosio, S., and Kostakos, V. Identity Crisis of Ubicomp?: Mapping 15 Years of the Field's Development and Paradigm Change. UbiComp '14, ACM (New York, NY, USA, 2014), 75–86.
31. Lord, C., Hazas, M., Clear, A.K., B. O. W. R. M. J., and Friday, A. Demand In My Pocket: Mobile Devices And The Data Connectivity Marshalled In Support Of Everyday Practice. To Appear CHI '15, ACM (New York, NY, USA, 2015).
32. Lyons, D. The Impact of Data Caps and Other Forms of Usage-Based Pricing for Broadband Access. Working Paper no. 12-27, Mercatus Center at George Mason University, 2012.
33. Lyons, D. Innovations in Mobile Broadband Pricing. Working Paper no. 14-08, Mercatus Center at George Mason University, 2014.
34. Odlyzko, A., Arnaud, B. S., Stallman, E., and Weinberg, M. Know Your Limits: Considering the Role of Data Caps and Usage Based Billing in Internet Access Service. Public Knowledge, May 2012.
35. Okune, A. Release of Google and iHub Research mobile Internet usage field study survey results from Kenya and Ghana. http://community.ihub.co.ke/blogs/11460/release-of-google-and-ihub-research-mobile-internet-usage-field-survey-results-from-kenya-and-ghana, 2012.
36. Rahmati, A., Tossell, C., Shepard, C., Kortum, P., and Zhong, L. Exploring iphone usage: The Influence of Socioeconomic Differences on Smartphone Adoption, Usage and Usability. MobileHCI '12, ACM (New York, NY, USA, 2012), 11–20.
37. Ravenscraft, E. Facebook Releases Facebook Lite, Drastically Reduces App Overhead. http://lifehacker.com/facebook-releases-facebook-lite-drastically-reduces-ap-1681768408, 2015.
38. Roto, V., Geisler, R., Kaikkonen, A., Popescu, A., and Vartiainen, E. Data Traffic Costs and Mobile Browsing User Experience. In *Proceedings of the 4th MobEA Workshop on Empowering the Mobile Web* (Edinburgh, Scotland, May 2006), 1–6.
39. Sambasivan, N., and Cutrell, E. Understanding Negotiation in Airtime Sharing in Low-income Microenterprises. CHI '12, ACM (New York, NY, USA, 2012), 791–800.
40. Sambasivan, N., Lee, P., Hecht, G., Aoki, P. M., Carrera, M.-I., Chen, J., Cohn, D. P., Kruskall, P., Wetchler, E., Youssefmir, M., and Larssen, A. T. Chale, How Much It Cost to Browse?: Results from a Mobile Data Price Transparency Trial in Ghana. ICTD '13, ACM (New York, NY, USA, 2013), 13–23.
41. Sani, A. A., Tan, Z., Washington, P., Chen, M., Agarwal, S., Zhong, L., and Zhang, M. The Wireless Data Drain of Users, Apps, & Platforms. *SIGMOBILE Mob. Comput. Commun. Rev. 17*, 4 (Dec. 2013), 15–28.
42. Sen, S., Joe-Wong, C., Ha, S., Bawa, J., and Chiang, M. When the Price is Right: Enabling Time-dependent Pricing of Broadband Data. CHI '13, ACM (New York, NY, USA, 2013), 2477–2486.
43. Sen, S., Joe-Wong, C., Ha, S., and Chiang, M. A Survey of Smart Data Pricing: Past Proposals, Current Plans, and Future Trends. *ACM Comput. Surv. 46*, 2 (Nov. 2013), 15:1–15:37.
44. United States Government Accountability Office. Broadband Internet: FCC Should Track the Application of Fixed Internet Usage-Based Pricing and Help Improve Consumer Education. http://www.gao.gov/assets/670/667164.pdf, 2014.
45. Vermeulen, J. Mobile data bundle price comparison. MyBroadband, 2015. http://mybroadband.co.za/news/cellular/118127-mobile-data-bundle-price-comparison.html.
46. Wyche, S. P., Smyth, T. N., Chetty, M., Aoki, P. M., and Grinter, R. E. Deliberate Interactions: Characterizing Technology Use in Nairobi, Kenya. CHI '10, ACM (New York, NY, USA, 2010), 2593–2602.
47. Xu, Q., Erman, J., Gerber, A., Mao, Z., Pang, J., and Venkataraman, S. Identifying Diverse Usage Behaviors of Smartphone Apps. IMC '11, ACM (New York, NY, USA, 2011), 329–344.