On the Free Bridge Across the Digital Divide: Assessing the Quality of Facebook's Free Basics Service

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ABSTRACT

Free Basics is an initiative backed by Facebook to provide users in developing countries *free* mobile Internet access to selected services. Despite its wide-spread deployment and its potential impact on bridging the digital divide, to date, few studies have rigorously measured the quality of the free Internet service offered by Free Basics. In this short paper, we characterize the quality of the Free Basics service offered in Pakistan and South Africa along three dimensions: (i) the selection of accessible Web services, (ii) the functionality of those services, and (iii) the network performance for those services. While preliminary, our findings show that data-driven studies are essential for having more informed public debates on the pros and cons of the current design of the Free Basics service.

1. INTRODUCTION

Internet.org [1] is a consortium founded and led by Facebook since 2013 with the goal of bringing affordable Internet access to everyone in the world. Free Basics is the flagship initiative by Internet.org, offering *free* access to select Web services in partnership with mobile (cellular) service providers in developing and under-developed countries around the world. As of May 12^{th} 2016, Free Basics has been deployed in over 40 countries in Africa, Asia, and Central and South America, with a total population of over 1.26 billion (22% of world's population) [2].[1] Compared to developed countries, these countries have low Internet penetration rates (on average less than 20.4% of their population access the Internet) [3]. However, mobile phone usage rates in these countries are very high (on average about 101.7%[2] [4]), making mobile phone users a ripe target for expanding Internet usage. Free Basics, if successfully deployed worldwide, has the potential to bridge the digital divide [5].

Our study of Free Basics is motivated by the following high-level question: *Free Basics is free, but at what quality?* Today, beyond the limited information provided by Free Basics themselves, there is little measurement data on the quality of Free Basics services or how the service quality is affected by Free Basics' design. As we show in this work, gathering data on Free Basics is challenging as existing measurement infrastructures that use the traditional Internet (e.g., PlanetLab [6] and Measurement-Lab [7]) cannot reach into or be reached from the walled Internet of Free Basics services and users. However, data-driven studies of Free Basics are necessary to help inform the public debates about Free Basics, which in early 2016, have led to Indian telecommunication regulators blocking Free Basics to over a billion potential users [8, 9].

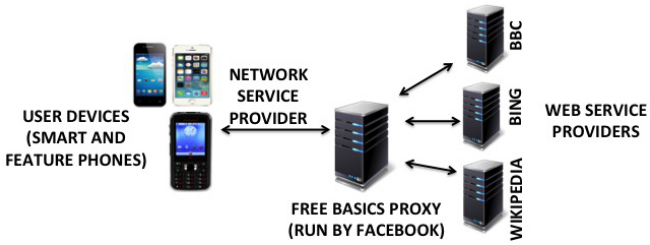

Figure 1: Free Basics architecture

How Free Basics works Before we outline the research questions motivating our study, it is useful to understand the service architecture of Free Basics. As shown in Figure 1, the Free Basics service comprises three independent service providers: (i) *network service provider:* the cellular carriers that agree to carry data for any Free Basics service at no

[1]Free Basics' deployment is also rapidly expanding with eight countries, including Nigeria with 180 million people, added to the list between May 1^{st} and Aug 15^{th} 2016.

[2]>100% because people can have multiple subscriptions

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cost to the end user, (ii) *Free Basics proxy service provider:* all Free Basics traffic is routed via proxies that are currently run by Facebook, and (iii) *web service providers:* to have their services accessed by Free Basics users, web site operators are required to first re-design their services following a set of technical requirements [10] and next apply to have their service approved by the proxy service provider [11]. The Free Basics platform is open to include any web service that meets the stated technical requirements (e.g., absence of JavaScript, high resolution images, videos or iFrames).[3] Such restrictions are put in place to support the target population of mobile users in developing regions, where mobile devices may not have full Web browsers and must access the Internet via WAP or similar technologies [12].

Any mobile subscriber of the participating network service providers can access (free of charge) the list of approved web services by going to `freebasics.com` using their mobile browser or by installing the Free Basics mobile application [13] (while connected to their cellular provider's network).

Our goal: Assess the QoS of Free Basics In this paper, our focus is on understanding the impact of Free Basics architecture on the Quality-of-Service (QoS) offered by Free Basics in practice. Specifically, we assess the QoS offered by the three service providers comprising Free Basics:

1. *Proxy service:* We characterize the selection of web services accessible via proxy on Free Basics.

2. *Web services:* We compare the functionalities of web services tailored for Free Basics to their unmodified versions on the Internet.

3. *Network service:* We analyze the network performance (measured as bandwidth, latency, and page download times) for Free Basics traffic compared to that for paid traffic to the same site on the same carrier.

We perform the above analyses using data from a preliminary study of Free Basics deployments in two countries, namely Pakistan and South Africa. The data for our study was gathered between April and August 2016. At a high-level, our measurements show that while several tens of web services are accessible on Free Basics, their functionality is somewhat restricted and the network performance for Free Basics traffic is poor (compared to paid network access). We highlight opportunities for a more informed public debate with our findings. However, we do not think that our measurement results by themselves are sufficient to make a strong case for or against FreeBasics. We conclude the paper by outlining our future plans for extending this work.

2. MEASUREMENT METHODOLOGY

To assess the QoS of the three service providers comprising Free Basics, we need to gather data on (a) the set of Free Basics web services, (b) the webpages of these services to analyze the functionality they offer and the network performance while downloading them, and (c) the webpages of the same web services on the normal Internet, to compare the QoS of a Free Basics service with the QoS of the normal version (using paid access).[4]

To collect the above data, we need to access Free Basics service providers. However, we found that access to Free Basics (including its proxies and web services) is restricted to mobile devices registered with a cellular service provider (i.e., with a SIM) in a country where it is offered. These restrictions make measuring Free Basics challenging as no network measurements from a machine outside of a Free Basics provider can reach a Free Basics proxy or the sites it serves. To measure Free Basics, at a minimum we need a physical mobile device connected to an appropriate Free Basics network provider in the country where it is deployed.

Figure 3: Experimental setup

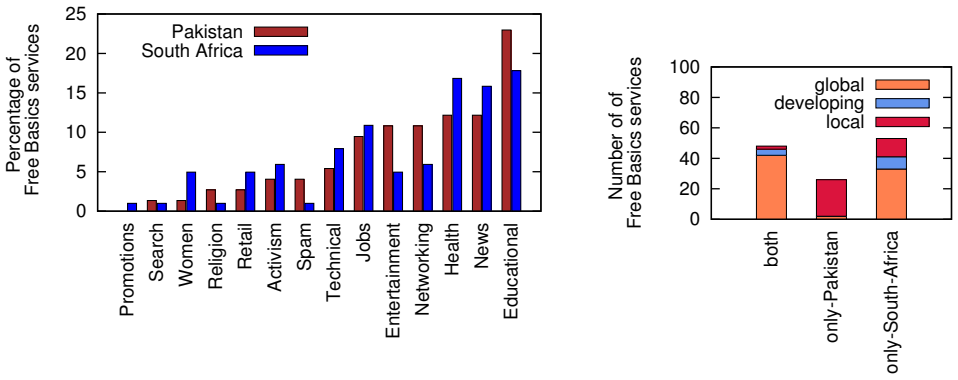
Experimental setup To measure Free Basics, we create experimental testbeds in the Lahore University of Management Sciences in Pakistan and University of Cape Town in South Africa. The authors from each of these two locations set up a smartphone with the necessary SIM connection. This smartphone acts as a Wi-Fi hotspot with a desktop tethered to it. We use a remote connection to the desktop to measure Free Basics via crawler scripts (with browser user-agent spoofed to an appropriate mobile web browser) and network monitoring tools. We show this as a diagram in Figure 3.

Data gathered Using our testbed, we gathered the following data: (a) the list of all web services accessible via Free Basics in both Pakistan and South Africa; (b) the homepages of all web services available in Pakistan and some additional pages for a subset of services for network performance analysis (described in more detail in Section 3.3), and (c) the pages for the normal Internet versions of the same services, over the same cellular provider but with paid network connection (where downloads count against a data plan unlike Free Basics content). We extracted the URLs for downloading the normal Internet versions of the web services from their corresponding Free Basics URLs in an automated way.[5]

[3]We validated this using our own web service submission.

[4]Throughout this paper we use the term *normal* to refer to sites outside of the Free Basics ecosystem.

[5]Currently, Free Basics URLs use a common format, "https://http[s]-[subdomains-separated-by-dashes]-[domain]-[tld].0.freebasics.com/[URI]?iorg_service_id_internal=[...]", where the corresponding URL is "http[s]://subdomain.domain.tld/URI". For example, the Free Basics URL https://http-example-com.0.freebasics.com/test/?... can be converted to the non zero-rated version http://example.com/test.



(a) Service categories (b) Service relevance

Figure 2: Categories of Free Basics services in Pakistan and South Africa

3. ASSESSING QOS OF FREE BASICS

In this section, we characterize the selection of Free Basics web services and compare the functionality and network access quality of these web services to their normal Internet counterparts (using paid access).

3.1 Selection of accessible web services

We explore the web services accessible via Free Basics deployments in Pakistan and South Africa. As of May 2016, there are 74 services in Pakistan and 101 in South Africa. The service listing in each country comes with a brief description of what each service does. We use these descriptions to manually categorize the services according to their functionality, as shown in Figure 2(a). We see a significant fraction of services in the education, news, health, networking, entertainment and jobs categories.

We further manually categorize services according to whether they are relevant to a global audience, country-specific audience (local), or to an audience in a developing region (Table 1). Figure 2(b) shows the proportion of services in each relevance category. We also split the services based on whether they are available in both countries, or only in one specific country. The figure shows that a significant fraction of globally relevant services are available in both countries, and that Pakistan's Free Basics menu has a higher proportion of locally relevant services compared to South Africa.

Relevant context	Characteristics
global	news, education, technical-knowhow, search etc., that are useful to anyone in the world
developing	information on manual farming, sanitation education, e.g., protection against mosquitoes and viruses (Malaria, Zika, Ebola, HIV)
local	news, entertainment, retail information, etc., that are locally relevant, mostly with native language support

Table 1: Categorization criteria for Free Basics services based on relevance

Figure 4(a) and (b) characterize the popularity of the Free Basics services, based on the Alexa website rankings *for that country*. Figure 4(c) characterizes the services based on their *global* popularity. The figures show that very popular content globally (presumably the "basics" in Free Basics) is often included in Free Basics, including Facebook, Wikipedia, Bing and BBC. However, these popular sites account for a small fraction (≈20%) of the available services, while other services included in Free Basics fall below the top 2000 globally popular services, or top 500 nationally popular services, as ranked by Alexa. Another interesting thing to see is how the service list grows over time. We detail such future works in Section 4.

A key take-away is that many globally/nationally popular services do not participate in Free Basics, but a wide variety of sites across multiple categories do. An important question is whether services with these characteristics (small number of globally and nationally popular services) are considered useful to Free Basics users. Answering this question requires field studies with Free Basics users, which is beyond the scope of this work.

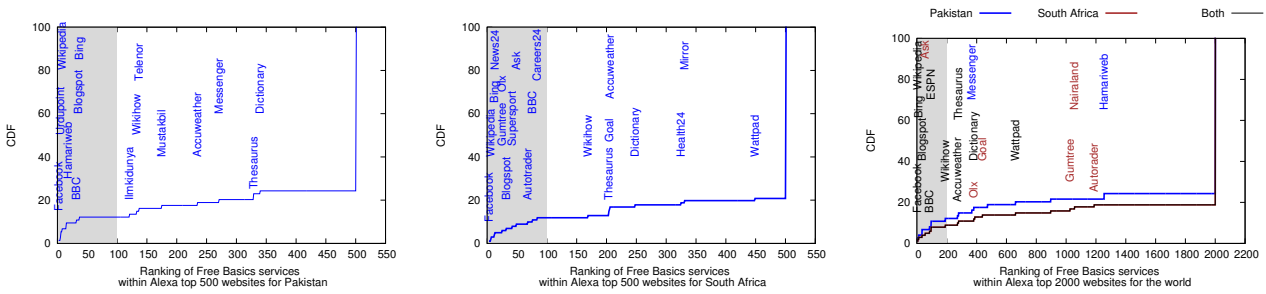
Interestingly, we find about 5% of the combined services in Pakistan and South Africa, to be somewhat dubious. These are listed as "spam" in Figure 2(a)). Table 2 lists these websites and the reason why we consider them dubious. Some of these services are not available, returning an HTTP 404 error. Others generate ISP warnings that accessing the service will incur data charges, even though they should be accessible at no charge as part of Free Basics. Finally, there is the case of an unremarkable individual's personal Facebook page,[6] included as a Free Basics service.

Service	Description
002CoSMos, newsbyte.org, roktim.net16.net, techhints.in	HTTP 404 error on homepage
VOA news, bolloywood-king.in, mujahid islam	Data warning on homepage
www.facebook.com/***	Personal Facebook page

Table 2: Dubious Free Basics services in Pakistan

These examples suggest that the consortium that decides the list of services to be part of Free Basics might not necessarily be checking the services beyond ensuring that they

[6]The username is elided for privacy reasons.



(a) Services in Alexa top 500 (Pakistan)

(b) Services in Alexa top 500 (South Africa)

(c) Services in Alexa top 2000 (Global)

Figure 4: Popularity of Free Basics services in Pakistan and South Africa

meet the technical requirements. While additionally controlling content for quality may seem reasonable at face value, and important concern is how to do so without the perception (or realization) of censorship. We believe this to be an important issue needing careful attention as Free Basics grows.

3.2 Functionality of accessible web services

To understand the impact of Free Basics' technical requirements for participation on service quality, we compare the Free Basics versions of services with their normal Internet counterparts. Specifically, we download the homepages of all Free Basics services in Pakistan, for both the Free Basics and the normal Internet version.

We test these sites using URLs that correspond to the same content available both in the paid and the free versions of the web services, thus enabling an apples-to-apples comparison. The structure of these corresponding URLs is described in Section 2. A concern is that the content for Free Basics and paid versions of the site may differ due to caching at the Free Basics proxy. We tested and found no evidence of caching; rather, the main content was identical (except for changes such as elimination of JavaScript).

Effect of technical specifications: Figure 5(a) shows a CDF of the ratio of the sizes of these homepages, normal compared to Free Basics. We observe that 80% of the services have at least bigger sizes and potentially richer content for the paid version, compared to the Free Basics version. E.g. `MashAllah ElecTronics` and `Pharmaceutical Guidelines` are 15x-18x larger in the normal versions. This difference can be attributed to high resolution images and multiple JavaScript files in the paid version, while only small images and no JavaScript are present in their Free Basics counterparts.

Further inspection of the services' homepages reveals the absence of any contextual and embedded advertisements in the Free Basics version of the services. The lack of advertisements is possibly due to the restriction on using JavaScript, which is commonly used to fetch and display ads. This restriction raises the interesting question of economic incentives of the web service providers, who might find it difficult to monetize their services in Free Basics.

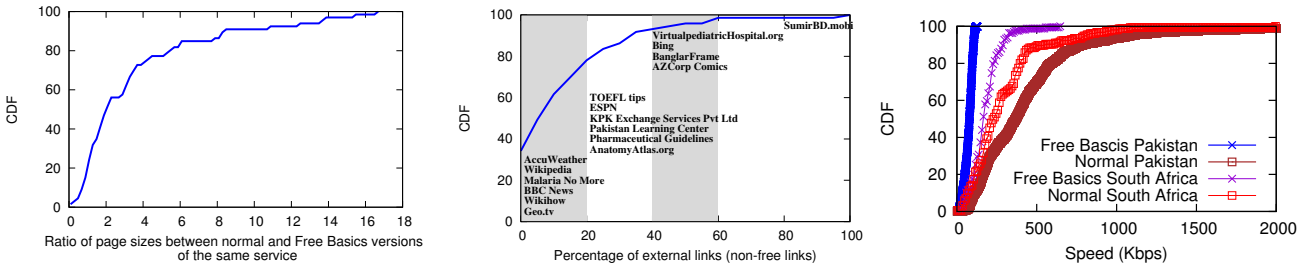
The technical specifications are put in place to support the target population of mobile users in developing regions, where mobile devices may not have full Web browsers and must access the Internet via WAP or similar technologies [12]. However, the functional restrictions on Free Basics services and their implications for the number of sites participating (and the content they provide) require further investigation and discussion. For example, determining whether the users like the offered services, despite functional restrictions, will require field studies with Free Basics users.

Effect of walled garden: Free Basics offers a limited set of services; accessing any Internet destination beyond that set is not blocked but will incur charges, with appropriate warnings shown to the user. To understand the impact of this "walled garden" on the user, we approximated the size of the "garden" by visiting every link from the homepage of every Free Basics service to determine whether the result was a warning page indicating that the visited link is outside of Free Basics.

Figure 5(b) plots the CDF of the percentage of URLs linked in the homepage of the Free Basics services in Pakistan that are outside the Free Basics domain and give data warnings. There are some services like Accuweather, BBC and ESPN on the left, which are mostly self-contained. However, 60% of the services have external links, which will cause breaks in the user browsing experience. In some cases, such as `VirtualpediatricHospital.org`, `SumirBD.mobi`, 80-90% of the listed URLs are external links—rendering such services effectively useless.

An interesting example of this comes from the Bing search engine, which is part of Free Basics in both South Africa and Pakistan. Table 3 shows the result for five representative searches in Pakistan, the number of results returned for each search, and number of those results that are accessible using Free Basics. The key take-away is that the vast majority of Bing search results cannot be followed by Free Basics users without incurring data charges.

Interestingly, we observe that it should be relatively easy to modify search output to rank the results based on their accessibility within Free Basics. This would improve the user experience for all the queries in Table 3, as Free Basics has significant number of services related to education, news, health and job portals. This trade-off between *offering a good user experience while keeping users restricted within the walled garden vs. offering some tantalizing con-*



(a) Ratio of homepage sizes (b) External links at home page of Free Basics services (c) CDF of page fetch speeds

Figure 5: Functionality and network quality of Free Basics services in Pakistan and South Africa

Search query	#results in first page	#Free Basics results in first page
Top universities in Pakistan	10	2 (both Wikipedia)
Pakistan news	13	0
Cricket	13	2 (1 Cricinfo, 1 Wikipedia)
Dengue prevention	10	1 (Wikipedia)
Jobs in Pakistan	10	0

Table 3: Functional breaks with limited number of Free Basics services returned by traditional search engines

tent out of reach of the free program to give users a glimpse of the potential of the broader Internet, is open for debate. Again, determining the merits of these approaches requires field studies.

3.3 Network performance

To measure the network service quality of Free Basics services, we take three representative services in Pakistan - BBC, Cricinfo and Mustakbil (a Pakistani job portal) and perform the following experiment. We download the landing page of each service and also all pages linked to this first page. We start this download simultaneously for the Free Basics version of the service, and the normal mobile version with the paid connection. We log the download time and the size for each page, which are used for head-to-head comparison between these Free Basics services and their paid counterparts. We do the same experiment for BBC Free Basics and BBC paid versions in South Africa.

Page fetch speeds Figure 5(c) shows the CDF of network speeds observed for the two versions of the same services. The CDF is computed over 346 HTML pages of the Free Basics version and 560 HTMLs of the normal version in Pakistan and 155 HTML pages of Free Basics version and 166 HTMLs of normal version in South Africa.

We see a marked difference in the two speed distributions in Pakistan, the median speed being 4 times slower for Free Basics (80 Kbps), compared to the paid version of the same service (320 Kbps). The curve for the paid services shows a wide range of speeds typical of cellular broadband access, and indicating that the provider has a capacity greater than 1Mbps. However, Free Basics downloads never experience more than 128 Kbps, strongly suggesting that Free Basics traffic is throttled to a fraction of capacity.

The difference between the paid and free versions of BBC in South Africa is less than that in Pakistan. Still, in South Africa too, the free version never exceeds 600 Kbps, while the paid version sees more than double those peak speeds. In both Pakistan and South Africa, it is difficult to attribute performance differences to carrier-imposed throttling, proxy-imposed throttling, or path inflation on the path that includes the proxy. Isolating the source is part of our ongoing work.

Page fetch times Figure 6 shows the effect of download speeds on user experience, the metric being page fetch times. For the four services, we see a median increase of 2 to 6 seconds in the page fetch times. The difference in page fetch times is also service dependent, Cricinfo seeing the worst delay followed by BBC and Mustakbil. This ordering follows the page size distribution of the services, where Free Basics version of Cricinfo had the largest pages, followed by BBC and Mustakbil. Thus services with richer content will lead to a substantially worse user experience.

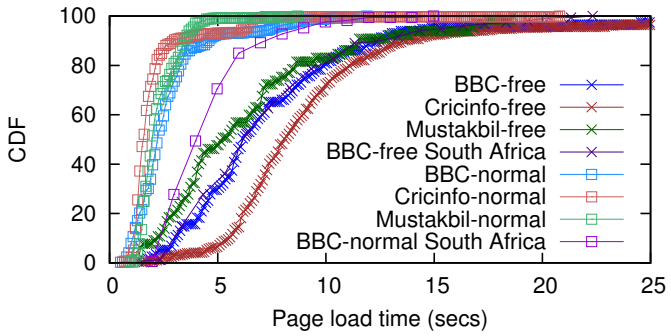


Figure 6: CDF of page fetch times by service

We tested whether different services within the same country saw differential service, and found no evidence of this (i.e., Free Basics performance was neutral with respect to service). Specifically, we compared performance between downloads of similar-sized pages from different services (not shown), and did not see any performance differences across the services.

Effect of proxy Xu et al. [14] found that the relative network locations of proxies between clients and servers can significantly impact performance. We ping the IP addresses con-

country	freebasics.com average ping delay (ms)	direct website average ping delay (ms)	freebasics.com minimum ping delay (ms)	direct website minimum ping delay (ms)
Pakistan	326.8	bbc.com - 297.15 cricinfo.com - 76.515 mustakbil - 346.25	299	189 54.4 315
South Africa	714.12	bbc.com - 460.5	494	255

Table 4: Difference in ping delays between the Free Basics proxy and direct access to the web services

tacted for freebasics.com traffic to understand their network distance from clients. Interestingly, the reverse DNS name for these IPs is a hostname ending with facebook.com or fb.com (which verifies the proxy based architecture in Figure 1 as documented by Facebook). We issue traceroutes and use city codes in reverse DNS records for last-hop router IPs to determine that the proxies we observed for Pakistan are in Europe and those for South Africa are in the US.

Table 4 shows the ping latency from our client in Pakistan to the proxy, and also to the servers hosting the normal versions of BBC, Cricinfo and Mustakbil. As seen from the table, the delay to the Free Basics proxy is relatively high (300 ms), largely due to the proxy being located in Europe (about 5000 miles from the client in Pakistan). This delay is six times larger than the delay to cricinfo.com, which is hosted in Pakistan, and more than 50% higher than the latency to bbc.com (likely hosted in Asia). Interestingly, the delay to mustakbil is essentially the same as to the Free Basics proxy, likely indicating that the service is hosted in Europe. Similar differences in ping delays are seen in South Africa, between the Free Basics proxy and the direct access to bbc.com.

Taken together, the performance results indicate that Free Basics users see poorer network performance to free sites than to paid ones. Whether this performance is tolerable to most users, and whether this is an acceptable price to pay for free service, requires further investigation with user studies and policy makers.

4. DISCUSSIONS & FUTURE WORK

This section further discusses the pros and cons of the Free Basics design. We also outline our plans to scale our current study and highlight some important aspects of Free Basics that are beyond the scope of this paper, but merit attention in future studies.

Is gate-keeping by proxy necessary? One of the widely debated Free Basics design choices relates to the gate-keeper role played by Facebook. Though we agree that the technical specifications are well-justified (e.g., needed to make the services accessible to resource-constrained feature-phone users), it is unclear why these cannot be enforced by a basic transcoding proxy that strips web services of excess functionality (e.g., JavaScript) on the fly to match the desired technical specifications [10]. Such a design would alleviate the need for individual web service operators to redesign their services and separately request Facebook to approve their services. From a user's perspective, such a design would tear down the wall around Free Basics services, make most traditional Internet services accessible, and significantly improve the user experience by limiting the number of broken (paid) links, when browsing (see Section 3.2).

While the transcoding proxy described above has the potential to open up the walled garden of Free Basics services, it might raise incentive concerns for network service providers (who might see a steep decline in the conversion rate of their Free Basics users to paid users[7]).

Furthermore, the decision to have all Free Basics traffic transit via the proxy raises two important concerns. First, as shown in Section 3.3, the proxies are often located (geographically) far from the Free Basics users and web servers, contributing to increased round-trip times and page download times for Free Basics users. Second, the proxy service provider has access to all, mostly unencrypted, end-user traffic. As an example of some of the potential privacy risks, the URIs exposed to Free Basics revealed information such as user locations (e.g. from weather query patterns in services like Accuweather) and political interests (e.g. from news browsing patterns in services like BBC). As the proxy provider, Facebook states that they only inspect domain names and traffic volumes, and that they (curiously) store any cookies "in an encrypted and *unreadable* format" [10].

Is Free Basics violating net neutrality? Many have raised network neutrality concerns regarding Free Basics, most notably in India [8, 9]. We found that in the two examples of Free Basics deployments that we studied, traffic for Free Basics received much worse performance than normal (paid) Internet traffic; however, all content within Free Basics received the same performance. Whether this constitutes a net neutrality violation is a matter of policy and is beyond the scope of this work. Another aspect of Free Basics that impacts net neutrality is differential pricing for content. In this sense, Free Basics may provide participating zero-rated services an advantage over those that do not participate. Understanding the implications of this on net neutrality is important, but also outside the scope of this work.

Future work: Scaling our study We are currently working towards scaling our QoS measurements of Free Basics along different dimensions: (i) *number of countries*: we will recruit volunteers to measure the QoS of Free Basics deploy-

[7]Facebook advertises the fact that nearly 50% of Free Basics users convert to paid Internet users within the first month of Internet use as an incentive for network carriers to offer Free Basics.

ments in more countries, (ii) *number of locations in each country*: we are implementing an Android (mobile) app to conduct measurements in the background, so our volunteers can easily measure at various locations using only a phone, (iii) *across time*: Free Basics deployments are still in their infancy. We plan to monitor how the set of accessible web services changes over the period of several months in several countries, and (iv) *across cellular technologies*: in this paper, we used high-end phones featuring the latest cellular technologies like LTE. A recent study [12] indicates that the majority of phones in developing countries are feature phones, supporting only older cellular technologies (3G, 2G, and GSM). This motivates the need to characterize performance for other cellular technologies and older devices.

Future work: Need for studies of Free Basics users The scope of this paper is limited to characterizing available Free Basics services and the performance for accessing them. Evaluating user satisfaction with Free Basics service choices, their free access to those services, and the quality of network performance they are given to access them, requires focused field studies. Such studies are orthogonal and complementary to our focus. In particular, we hope that recent efforts towards understanding the usage of *zero-rated* services (where network service providers carry traffic for specific Internet services for free and charge for others) would be extended to cover Free Basics users as well [15].

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