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Exploring the determinants of Internet Usage in Nigeria: a micro-spatial approach

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Abstract. The dearth of Information Communication Technology (ICT) infrastructure in the Sub-Saharan Africa region underscores the argument that the spread of broadband infrastructure can foster internet adoption in the region. Consequently, the aim of this paper is to present results on the determinants of internet adoption in a sub-Saharan African country. Drawing on a dataset of households in Nigeria, this study presents findings on the demographic, socio-economic and infrastructure factors that predict internet usage in Nigeria. The novelty of our analysis stems from a unique dataset constructed by matching geo-referenced information from an inventory of network equipment to a nationally representative street-level survey of over 20,000 Nigerians, by far one of the largest technology adoption surveys in sub-Saharan Africa to date within the information systems literature. The results are discussed and concluding remarks highlighting next steps are made.

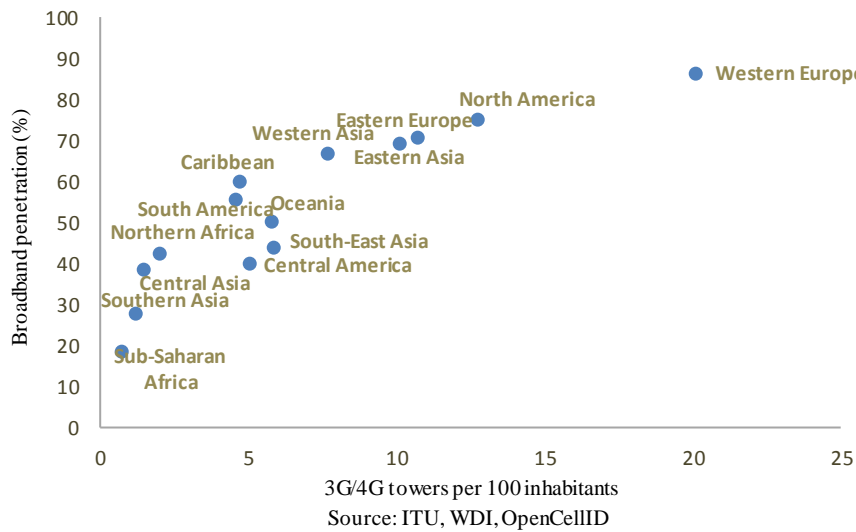
Keywords: internet usage; broadband; socio-economic determinants; technology diffusion; micro-spatial approach

1 Introduction

Internet access is perhaps one of the most significant indicators of human and socio-economic development. It fosters productivity and innovation (Avgerou, 2008; Paunov and Rollo, 2016), social interactions (Liang and Guo, 2015) and reduces communication and search costs (Beard et al., 2012). Yet, there is a digital divide in the level of internet access among developing countries, especially those in sub-Saharan Africa (SSA) compared to the rest of the world. Within SSA, the lack of internet access is a recognized barrier to the adoption of information communication technologies (ICTs) (Afolayan et al. 2015). This argument seems to be supported by regional broadband statistics, as shown in Fig. 1 where SSA is portrayed to have the lowest levels of internet penetration and wireless broadband infrastructure per capita, relative to other regions of the world. While previous studies have shed light on the regional variation in internet adoption by focusing on the determinants of internet penetration in the context of the “digital divide” (e.g. Oyelaran-Oyeyinka and Lal, 2005; Chinn and Fairlie, 2010), these studies often employ infrastructure measures/proxies (such as fixed telephone lines per sq. km, main telephone lines per capita, etc.,) thereby overlooking the peculiar nature of broadband infrastructure in the SSA region. More specifically, we note that internet use across the SSA region is undertaken mainly via wireless broadband access, rather

than fixed-line broadband. Thus, in this paper, we draw on a unique dataset that combines geo-referenced (longitude and latitude) information on 3G and 4G wireless network equipment to examine factors that predict of internet usage in Nigeria – a sub-Saharan country. Consequently, this study offers two potential contributions to the literature.

Fig. 1. Internet penetration and broadband infrastructure, 2017



First, unlike previous studies, we demonstrate a measure of broadband infrastructure is micro-spatial in nature, i.e., it is based on the density or concentration of 3G and 4G equipment around each household's dwelling over specified spatial domains. To achieve this, we match street-level information from the technology survey to the Global Positioning System (GPS) coordinates of 3G and 4G cell towers. This micro-spatial approach renders more nuanced and invaluable insights on whether/how spatial proximity or access to wireless internet connection shapes adoption decisions at the local level. After all, without connectivity, it is practically impossible to adopt/use broadband services. Furthermore, this spatial approach also embodies the reality that signal quality, a key determinant of actual usage behaviour, is shaped by the physical proximity of users to broadband connections (Neto, et al. 2005; DeStefano et al. 2018). Hence, in addition to treating the spatial diffusion of wireless network infrastructure as an appropriate measure of broadband infrastructure, it is also a quality-weighted indicator that enriches our analysis.

Second, our focus on Nigeria provides a plausible and timely case study of the effect of broadband infrastructure diffusion on internet usage in SSA and the broader developing country context. Given that it accounts for the largest proportion (18%) of the entire SSA region's 1.03 billion population (World Development Indicators, 2018), we would argue that Nigeria is the most representative country of the SSA region.

Furthermore, ITU estimates indicate that more than 90% of the youth population in developed countries use the internet compared to 30% in less developed regions of the world. Considering that the proportion of Nigeria's population below 40 years is projected to reach 81% by 2030, broadband penetration is likely to have a significant role in shaping Nigeria's participation in an increasingly digitalized future economy. Finally, despite growing to become Africa's largest economy and one of the major emerging economies in the world, Nigeria epitomizes the co-existing low levels of internet penetration and ICT infrastructure deficit (The Economist, 2016). The remainder of this paper is organized as follows. In Section 2, we undertake a critical review of related literature on internet adoption and ICT infrastructure. This is followed by the model specification and the methods section. In Section 5, we discuss the results and conclude in section 6 highlighting next steps and expected contributions of our study to the information systems literature and policy.

2 Related Literature

The literature on internet adoption and penetration is large. Consequently, due to space constraints, the goal of this review is not to present an extensive discussion of existing literature. Rather, we highlight a gap in the use of proxy measures in accounting for technology adoption. A more comprehensive review can be found in Cardona et al. (2013).

A dominant strand in the literature pertains to cross-country studies aimed at evaluating the determinants of internet usage and penetration in the context of the digital divide in developing countries. One of such studies is Dasgupta, et al. (2005) who investigated the determinants of internet intensity (internet subscriptions per telephone mainline) for a cross country sample of 44 OECD and developed countries. Similarly, Chinn and Fairlie (2007) provide an analysis of internet penetration using a larger sample of based on panel data for 161 countries over the 1999-2001 period. They control for a range of macro-level determinants on telecoms prices, per capita income, education, age structure, urbanization, regulatory environment, etc. Although this study also controls for ICT infrastructure, their reliance on telephone density may not be applicable to the African context. Other internet diffusion/penetration studies use large cross-country samples from developing regions of the world (e.g. Chinn and Fairlie, 2010). A few studies however focus on internet penetration for more specific sub-groups/regions of the world such as OECD (Lin and Wu, 2013), The Americas (Galperin and Ruzzier, 2013), APEC (Liu and San, 2006), Africa (Oyelaran-Oyeyinka and Lal, 2005) and Asia (Feng, 2015). Greenstein and Spiller (1995) investigate the impact of telecommunication infrastructure (measured by the amount of fiber-optic cables employed by local exchange telephone companies) on economic growth in the U.S. Roller and Waverman (2001) investigate the linkages between broadband investment and economic growth across 21 OECD countries and 14 developing countries during 1970 to 1990. More recent studies have focused specifically on the impact of broadband infrastructure. For instance, Czernich et al. (2011) investigated the effect of broadband infrastructure on the economic growth for a panel of OECD countries over the period

1996-2007. However, they model this relationship by analyzing how broadband infrastructure (proxied by broadband penetration) shifts the growth parameter of technological progress within a macroeconomic production function setting. Tranos (2012) explored the causal effect of broadband infrastructure (internet backbone capacity) on the economic development across European city regions over the period 2001-2006 with ICT infrastructure found to stimulate economic development.

Three important observations can be gleaned from the above literature review. First, the cross-country studies tend to focus on the digital divide, attempting to explain internet adoption and penetration based on changes in economic, social, demographic and regulatory/institutional factors. Even when these studies attempt to account for the role of telecoms infrastructure, they do so by using variables such as personal computers per 100 people, main telephone lines per 100 people, customers' equipment (e.g. telephone set, facsimile machine), etc. Second, studies based on microdata tend to focus on developed country contexts, while also relying on infrastructure proxies that are analogous to the cross-country studies. Moreover, the developing country studies are not free from this problem too. Third, even studies that focus mainly on the effect of ICT infrastructure on economic measures and internet adoption also employ similar ICT infrastructure measures such as investments in telephone/broadband cables.

In comparison to the cited studies, we take a different approach by employing a true measure of internet infrastructure that is based on the prevalence of wireless network equipment (i.e. towers and radios). We then explore the effect of wireless network access on internet adoption at the individual level, based on physical proximity to broadband connection. Research has shown that variations in technology adoption are shaped by heterogeneity in geographical network access, such that the physical proximity to broadband connection or infrastructure can be expected to shape adoption decisions at the local level. For instance, it is well established that urban areas benefit from higher concentration of ICT infrastructure, which may enable social learning and adoption of ICT technologies (Liu and San, 2006). Hence, unless this type of analysis is undertaken, these disparities in network access may be inadvertently explained away as differences across individual income or demographic characteristics.

This paper is also related to a small and evolving body of studies that exploit spatial data towards analyzing the diffusion of telecommunications technologies. Our review shows that research conducted by Buys et al. (2009) and Hodler and Raschky (2017) come close to the line of inquiry pursued in this study. However, they differ significantly from this study in two crucial ways. Firstly, both studies conduct country-level spatial analysis while we adopt a micro-level spatial approach. Secondly, while the former investigates the determinants of mobile operators' spatial location of network sites across Sub-Saharan Africa, the latter explores the role of ethnic politics in shaping the spatial diffusion of mobile phone infrastructure in Africa. As far as we know, the closest relative to this study is DeStefano et al. (2018) where the authors investigated how the arrival of ADSL broadband technology influenced the IT-productivity gap among UK firms. Comparatively, this study is therefore the first to explore the individual-level

influence of broadband infrastructure on internet adoption using a micro-spatial approach, especially in a developing country context.

3 Model Specification

This study uses a probit model to examine the determinants of internet usage in Nigeria. Probit models are used when the dependent variable is dichotomous. We employ a set of explanatory variables in our model, namely: demographic factors include age, gender, marital status and religious affiliation; socio-economic factors such as expenditure, education, whether they are employed or not and a location variable indicating whether respondents live in rural or urban areas. Finally, we also include a micro-spatial infrastructure representing the number of internet infrastructure within a radius of where they live (i.e. towers) and the average tariff per megabyte of data used (tariff). Both towers and tariffs represent our infrastructure variables included in our model. Thus, our model is represented by the equation: Internet Use = f (age, gender, income and education, marital status, religious affiliation, towers, tariffs, urban).

We expect monthly expenditures (our proxy for income) to affect broadband adoption/usage positively. The probability of this adoption decision is also likely to rise for more educated individuals. However, the need for possessing an internet subscription, however, may fall for older and unemployed respondents. In terms of age, one could argue that, whereas younger individuals may have lower income, they tend to demonstrate a greater degree of technological affinity (Hübler and Hartje, 2016). We add a gender variable as an additional characteristic, given that the preferences and decisions of men are more dominant than the preferences of their spouse(s) in patriarchal societies (Bulte et al., 2016). Similar considerations can be extended to the marital status of an individual on the adoption of internet technologies. Finally, technology adoption decisions are often shaped by religious reasons, as some religious beliefs may restrict the adoption of conventional technological products (Fungáčová, et al., 2017). Hence, we control for the religious beliefs of each sampled individual.

To examine the effect of broadband infrastructure on internet adoption, used a measure that captures individual-level access to wireless broadband network. Hence, we employ a microspatial variable that captures the prevalence of wireless network infrastructure at the individual level. We calculate this variable using information from our two data sources in four steps. First, inspired by Hodler and Raschky (2017), we extract and map the 3G and 4G cell tower locations from OpenCellID (see figure B in the appendix section). Secondly, we extract and map the street-level dwelling locations from the survey data. Thirdly, to use both data for our purpose, we link them by overlaying the towers map with the dwelling location map. Finally, we compute a micro-spatial infrastructure variable as the total number of cell towers within 5-kilometer radius of everyone. This 5-kilometer specification is premised on the fact that network coverage in SSA is mainly based on base stations that can provide service up to a 5-10-kilometer

radius (Aker and Mbiti 2010, p. 209). We achieve this using the Stata ‘*spmap*’¹ command.

4 Method

4.1 Data Collection

To investigate the effect of wireless connectivity on internet usage, we rely on a unique nationally representative market survey of Nigeria carried out by Africa’s largest mobile operator, MTN² during April-July 2018. The MTN survey, which covers 730 localities (i.e., villages or towns), is by far and away one of the largest and most comprehensive technology surveys in sub-Saharan Africa to date. The data was collected via the use of paper questionnaire distributed to respondents in all 36 states of the country. Figure A in the appendix section plots the centroid GPS coordinates of surveyed areas at the municipality level. The wide geographical spread of the survey areas confirms the nationally representative nature of the survey. A total number of 21,844 observations were obtained for the final analysis. Our second data resource is the OpenCellID database which contains information on the micro-spatial independent variable (towers). The database contains raw information on the geo-location (longitude and latitude) of around seven million unique cell sites across the world (Hodler and Raschky, 2017). One key benefit of the OpenCellID database is the possibility to identify the technology (radio) type for each telecommunications tower (i.e. GSM, UMTS, LTE, etc.). This allowed us to identify the two wireless network classes: “UMTS” (third-generation technology, 3G) and the more advanced “LTE” (fourth-generation technology, 4G) types. Specifically, we identified a total of 13246 unique tower locations from the OpenCellID data consisting of 11470 3G and 1776 4G sites. These sites are geo-coded at the GPS (longitude and latitude)- level (see figure B in the appendix).

4.2 Measures

Our main dependent variable is represented by a broadband usage variable for the use of broadband services. To construct this indicator variable, we convert survey responses on broadband subscription using the question: “Which of the following telecommunication services³ do you use nowadays?”. We then calculate the dependent indicator variable as a dummy that takes the value “1” if “Data service (Accessing internet)” was selected in response to the question. Otherwise, a dummy value of “0” was assigned to the observation. Table 1 provides the summary statistics of the variables employed in this study. The internet adoption rate within our dataset is 12%, falling firmly within the same ballpark as the 13.7% and 15.2% broadband penetration rates reported by

¹ See <https://www.stata.com/support/faqs/graphics/spmap-and-maps/> for resources on the *spmap* command

² <https://www.mtn.com/> MTN is the market leader in the Nigerian telecoms industry, accounting for 40% market share. See statutory regulatory data at <https://www.ncc.gov.ng/stakeholder/statistics-reports/industry-overview>

³ The listed service options include “Voice services”, “Data service (Accessing internet)” and “Digital/2G services”.

Business Monitor International (BMI, 2018) and the ITU, respectively. The summary statistics in table 1 also indicate that there are on average 28 wireless network towers within 5 kilometers of each respondent's street. However, the standard deviation of 40 towers within the 5 kilometers radius suggests a reasonable spread or dispersion of the cell tower variable.

Table 1. Summary statistics of variables employed

Variable	Mean	Standard deviation
Internet adoption	0.119	0.324
Internet infrastructure	28.075	40.016
Expenditure ⁴	55055.25	79552.62
Tariffs	0.627	0.088
Age	43.974	18.394
Education	13.314	4.978
Male	0.561	0.496
Married	0.624	0.484
Unemployed	0.118	0.323
Christian	0.619	0.486

Note: Internet infrastructure: 3G/4G towers within 5 km of respondent; Expenditure: sum of expenditures on food, rent, fuel, clothing & healthcare; Age: age of the individual in years; Education: no of years of formal education; Male: Dummy = 1 if individual's gender is male; Married: Dummy = 1 if individual is married; Unemployed: Dummy = 1 if individual is unemployed; Christian: Dummy = 1 if individual's religion is Christianity; Tariffs: average tariff per megabyte (MB) of data use. Number of individuals: 21844

5 Results

Table 2 presents the marginal effects from baseline probit estimations. In column 1, we start by measuring the network infrastructure effects on broadband adoption: probability of adopting internet services, without any control variables or locality effects. Due to the cross-sectional nature of our data, we interpret these results as associations. It is clear from the results in columns (1) that a strong positive correlation exists between the concentration of broadband infrastructure around each individual and internet adoption. This coefficient is significant at the 1% level. From column 2 to 10, we add the control variables one by one, but the infrastructure coefficient remains statistically significant at the 1% level, albeit the magnitude of the coefficient drops. In column 11, we include locality effects to draw inference only from the variation in individual adoption decisions. Besides employing controls and locality effects, we use heteroskedasticity-robust standard errors clustered at the locality level that allow the data to be independent across localities by restricting the error terms to be correlated for individuals within the same areas on account of omitted regional characteristics.

⁴ Expenditure is in Nigerian Naira (1 Nigerian Naira = £0.0022 – as at 14 November 2019)

Table 2. Results of probit model for the determinants of Internet usage in Nigeria

Der var: Prob (internet)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
<i>towers</i>	0.0205*** [0.0015]	0.0194*** [0.0014]	0.0193*** [0.0014]	0.0197*** [0.0014]	0.0191*** [0.0014]	0.0171*** [0.0015]	0.0168*** [0.0015]	0.0171*** [0.0014]	0.0149*** [0.0018]	0.0146*** [0.0017]	0.0121*** [0.0018]
<i>expenditure</i>		0.0108*** [0.0010]	0.0117*** [0.0010]	0.0116*** [0.0011]	0.0116*** [0.0010]	0.0102*** [0.0010]	0.0096*** [0.0010]	0.0097*** [0.0010]	0.0098*** [0.0010]	0.0095*** [0.0010]	0.0074*** [0.0010]
<i>tariffs</i>			-0.0003*** [0.0001]	-0.0004*** [0.0001]	-0.0004*** [0.0001]	-0.0003*** [0.0001]	-0.0003*** [0.0001]	-0.0003*** [0.0001]	-0.0003*** [0.0001]	-0.0003*** [0.0001]	-0.0002*** [0.0001]
<i>age</i>				-0.1424*** [0.0066]	-0.1130*** [0.0068]	-0.1005*** [0.0070]	-0.1030*** [0.0069]	-0.1111*** [0.0071]	-0.1114*** [0.0071]	-0.1108*** [0.0042]	-0.1147*** [0.0061]
<i>married</i>					-0.0443*** [0.0052]	-0.0442*** [0.0052]	-0.0417*** [0.0051]	-0.0341*** [0.0052]	-0.0337*** [0.0052]	-0.0346*** [0.0052]	-0.0217*** [0.0046]
<i>education</i>						0.0473*** [0.0169]	0.0454*** [0.0164]	0.0405*** [0.0143]	0.0398*** [0.0139]	0.0384*** [0.0136]	0.0323*** [0.0107]
<i>christian</i>							0.0172*** [0.0065]	0.0255*** [0.0066]	0.0261*** [0.0066]	0.0246*** [0.0065]	0.0179*** [0.0050]
<i>male</i>								0.0515*** [0.0047]	0.0518*** [0.0047]	0.0495*** [0.0047]	0.0463*** [0.0036]
<i>urban</i>									0.0199** [0.0087]	0.0195** [0.0087]	0.0268*** [0.0078]
<i>unemployed</i>										-0.0475*** [0.0091]	-0.0416*** [0.0070]
<i>constant</i>	-1.7096*** [0.0478]	-2.2363*** [0.0648]	-2.2851*** [0.0644]	0.5212*** [0.1380]	0.0935 [0.1422]	-0.6895** [0.3018]	-0.6581** [0.2961]	-0.6434** [0.2671]	-0.6363** [0.2649]	-0.5643 [0.2623]	-0.2237 [0.2308]
Pseudo R-squared	0.0326	0.0512	0.0522	0.0889	0.0944	0.1127	0.1135	0.1222	0.1232	0.1251	-
Regional effects	No	No	No	No	No	No	No	No	No	No	Yes
Number of localities	730	730	730	730	730	730	730	730	730	730	730
Number of observations	21844	21844	21844	21844	21844	21844	21844	21844	21844	21844	21844

Notes: This table reports the marginal effect values from linear probability (random effects) models for predicting the effects of wireless network infrastructure on internet adoption. Standard errors clustered at the locality-level are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

As seen in Column 11, the infrastructure coefficient retains its statistical significance but drops further. Specifically, infrastructure coefficient of 0.012 suggests that a unit increase in the number of cell towers within 5km of a respondent increases the probability of internet adoption by 1.2%, which corresponds to an increase in the likelihood of adoption from around 12% to around 13.2% in an average respondent. Also, in the full specification in column 11, the coefficients on the control variables are consistent with intuition and they are all statistically significant at the 1% -level. For instance, older and unemployed respondents are less likely to adopt broadband services, whereas higher income earners, more educated individuals and urban dwellers are more likely to adopt the internet. For religion, being a Christian increases the probability of adoption. The positive coefficient on the male gender variable is consistent with the patriarchal nature of the Nigerian society, which indicates that the men are more likely to adopt internet services, perhaps reflecting the stronger socio-economic power of the male gender. Interestingly, in terms of the magnitude of the coefficients, we find age and gender to have the greatest effect on broadband adoption, with both coefficients indicating 11% and 5% positive impact on the probability of adoption, respectively. The age coefficient lends weight to our opening arguments on the implications of broadband adoption for the participation of the large projected youth population of Nigeria in an increasingly digitalized global economy in the future. For all the specifications in Table 2, the results also show that individuals in areas with a higher concentration of network infrastructure are more likely to adopt and use broadband services.

6 Concluding remarks and next steps

This paper presents first-stage results showing factors that influence internet adoption in Nigeria. Using geo-referenced information of an inventory of broadband network infrastructure, we employ a more appropriate micro-spatial measure of internet infrastructure based on 3G/4G network equipment at the local level alongside a range of explanatory variables to explain internet adoption in Nigeria. In general, the results obtained are economically important, and they can help explain the adoption patterns of broadband services particularly when network infrastructure effects are likely to play an important role in driving internet penetration. For instance, in many regions across developing countries, network coverage is usually the first modern technology of any kind (Aker and Mbiti, 2010). Hence, we would argue that the failure to control for this network infrastructure effect in the study of broadband adoption across developing countries could well result in significant omitted variable bias. Furthermore, the network infrastructure effect may also explain the nuances embodied in the varied adoption of broadband services across different regions, given that the quality of service (QoS) and user experience may well depend on the diffusion and reliability of the underlying network infrastructure.

Although the first-stage results presented in this paper revealed preliminary drivers of internet adoption, they also provide interesting avenues for further study which we aim to explore in subsequent analysis of the dataset. In the first place, the significant urban

variable shows that there are likely to be regional differences with regards to the factors that influence internet adoption in Nigeria. Given that Nigeria has one of the largest rural population in Africa (World Bank, 2015), we expect that further analysis testing the relationships in this study across rural and urban dwellers, will contribute significantly to the policy debate on bridging the urban-rural internet divide in Nigeria. Further, having microeconomic information that is representative of the national population of the type used in this research, permits clear visualization of the digital divide as an additional form of inequality that can hinder access to other internet-reliant technologies. For instance, the telecommunications sector in Nigeria is currently undergoing several policy changes, one of which is the granting of mobile money licenses to mobile network operators. Therefore, it is earmarked that further analysis with our data will explore diffusion constraints for other technologies covered in the survey data and how usage patterns might vary in different parts of the country. We hope that the results of these avenues of research will provide new insights that contribute to both policy and research.

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Appendix section

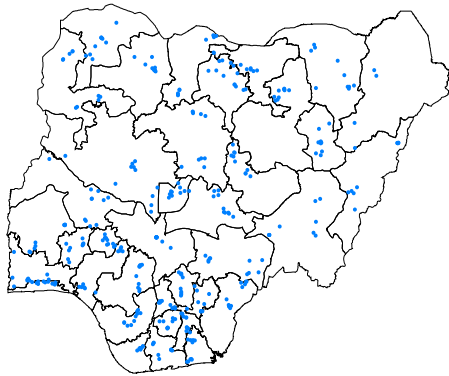


Fig. A. Nigerian map showing surveyed areas

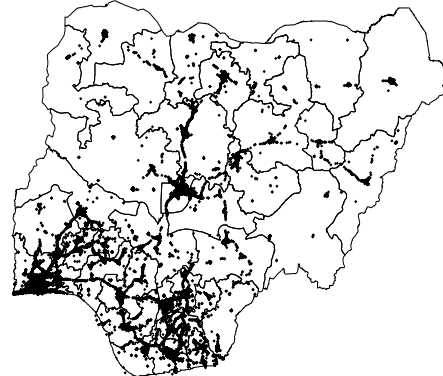


Fig. B. Tower sites in Nigeria (source: OpenCellID data)

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