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CONTENT

Vol 4, 2019 Issue, ISSN 2001-2837, Pages 41-50

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Next-Generation Wireless Networks for Uganda by 2025

Dorothy Okello[1], Derrick Sebbaale[2], and Geoffrey Mark Kagarura[2]

[1]Senior Lecturer, Department of Electrical and Computer Engineering, Makerere University P. O. Box 7062, Kampala, Uganda

[2]Assistant Lecturer, Department of Electrical and Computer Engineering, Makerere University, P. O. Box 7062, Kampala, Uganda

Email: {dkokello, dsebbaale, gmkagarura}@cedat.mak.ac.ug

ABSTRACT

Next-generation wireless networks entail a high degree of flexibility, efficient use of available radio resources and an energy-efficient operation at low operational costs. They typically integrate use of technologies such as spectrum management, interference mitigation and management, and energy efficient technologies. This paper projects the next generation wireless networks scenario of Uganda by 2025, when 5G connections are expected to have crossed the 1 billion mark globally. It builds upon an earlier scenario for Uganda's traffic profile by 2020 that focused on 3G and beyond. The paper identifies major environmental constraints that current and future network architectures will face, in particular deployment density and throughput requirements by 2025, when 5G networks are expected to be commercially available globally. Given the nature of investment required and the need for appropriate policy direction, it is important to map out Uganda's communications scenario for 2025. The paper compares the current and forecast traffic patterns of an urban area (Kampala District) and a fast-growing rural area (Gulu District). The wireless traffic model adopted forecasts throughput requirements as an aggregation of individual service requirements, service usage and user behavior. This paper focuses on voice, mobile Internet and video that are currently among the highly utilized services in Uganda. In similar studies for developed countries, next generation radio access networks are expected to deliver twenty times more throughput and capacity than current 4G/LTE networks while core networks are expected to handle a projected 1,000 times throughput increase, with a more flexible design that can cope with unpredictable demands more intelligently. The analysis for Uganda in 2025 reveals a more modest traffic growth. To meet future requirements with Uganda being largely rural by classification, there is need to stimulate demand and to foster public-private partnerships in addition to innovative spectrum management and efficient energy management.

Keywords: 5G, Capacity, LTE, Next-generation wireless networks, Traffic forecasting

1.0 INTRODUCTION

Since liberalization of the telecommunications sector, Uganda has witnessed remarkable growth in the sector. By 2015, the information and communication technology (ICT) sector was contributing 2.5% share of the GDP with direct employment of 1 million people (MoICT&NG, 2018). It was further estimated that over 1 million people, particularly youth, were also employed in ICT-related activities such as resale of value-added services and in

ICT hubs. Nevertheless, opportunity for growth abounds as Uganda still remains below the average for Sub-Saharan Africa. The GSM Association (GSMA) reported that by 2011, the mobile telecommunication sector was associated with 4.4% of the Gross Domestic Product (GDP) of Sub-Saharan Africa (GSMA and Deloitte, 2012). It had also created more than 3.5 million full-time equivalent jobs across both the formal and informal sectors.

Globally, the growth of demand in the telecommunication sector was expected to continue to grow even up to 2020, although at slightly slowing pace (Blume *et al.*., 2013). For instance, studies conducted in developed countries showed exponential growth and a 1,000-fold improvement in 2020 traffic compared to a 2010 reference (Blume *et al.*, 2013, Gelabet *et al.*, 2013, Zander *et al.*, 2013). It was also expected that second generation (2G) and third generation (3G) wireless networks would be replaced by fourth generation (4G) and beyond-4G networks (Blume *et al.*, 2013, Mogensen *et al.*, 2012). In terms of services, growth was expected in five major categories, web, video, peer-to-peer, wireless data and wireless voice (Kilper *et al.*, 2011). These services represented only a fraction of the then available or future services. In general, wireless and mobile Internet access were expected to emerge as a dominant technology in which wireless access would be abundant and virtually free (Zander *et al.*, 2013).

Statistics from Uganda Communications Commission (UCC) reveal an increase in internet penetration which is largely driven by a growth of mobile internet subscription (UCC, 2018). The percentage of individuals using the internet has grown from 0.2 per cent in 2000 to 24 per cent by year end 2017 (ITU, 2018a). This growth is attributed, in part, to the growing popularity and usage of smart phones in Uganda as well as a growth in demand for 3G/4G/LTE services and beyond. Such growth does need to address constraints including access to spectrum, sector-specific taxes on mobile terminals and usage, standardized rights of way due to significant investments required, and a collaborative public-private partnership approach to the sector's development (GSMA and Deloitte, 2012). Indeed, a review of the Uganda National Broadband Policy of 2018 has key principles that include open and universal access to broadband infrastructure, cross-sector infrastructure sharing including a "dig-once" approach to cater for all public utilities, a right mix of technology and network neutrality, and environmental consideration (MoICT&NG, 2018). In general, next-generation wireless networks entail a high degree of flexibility, efficient use of available radio resources and an energy-efficient operation at low operational costs (ITU, 2018). They typically integrate use of technologies such as spectrum refarming/aggregation, cognitive radio/software defined radio, beam forming and distributed multiple-input multiple-output (MIMO) antenna systems, interference mitigation and management, cooperative radio resource management, and energy efficient technologies.

2.0 THE CASE FOR 5G NETWORKS

Beyond 4G, trials for 5G networks are underway in a number of countries (ITU, 2018). 5G networks are expected to have significant broadband capacity, with download speeds of at least 100 Mbps, to support massive machine-to-machine communications as well as to provide low-latency, high-reliability service for time critical applications (ITU, 2018, Nguyen *et al.*, 2017). This will require deployment of innovative technologies including software defined networks (SDNs), network virtualization, and info-centric networking to make 5G networks faster, smarter and more cost-effective.

In addition to capacity constraints, 5G will require much more spectrally efficient technologies and spectrum allocations beyond what is in use for 3G and 4G networks. 5G is projected to use frequencies above 24 GHz which poses two additional challenges (ITU, 2018). Firstly, radio propagation at such frequencies is known to be very suspect to weather, in particular, rain – itself a common feature in tropical countries such as Uganda. Secondly, frequency bands above 24 GHz are already in use by various services such as satellite communications, weather forecasting, and monitoring of earth resources and climate change. Hence the need for regulatory policies that provide an enabling environment to attract investment in the development of virtualized, highly configurable and elastic networks to deliver 5G services in Uganda (O'Briain *et al.*, 2017).

In terms of penetration, the GSMA estimates 5G connections to reach 1.1 billion by 2025, and that this will represent 12 per cent of the total mobile connections (ITU, 2018). Since 2012, the International Telecommunication Union has been developing the international mobile telecommunication (IMT) standards for 5G (IMT-2020). The first commercial deployments are expected by 2020. Countries considering 5G services will do well to assess the value of different use cases proposed for 5G. These use cases include sharing of any type of content anytime, anywhere and through any device; easy access to digital textbooks or cloud-based storage of knowledge on the Internet; energy efficiency by supporting massive machine-to-machine communications and solutions such as smart grid, teleconferencing, and smart logistics and transportation; and broadband mobile service delivery and information exchange where broadband connectivity is treated with the same priority as access to electricity (ITU, 2018). It should be noted that the National Broadband Policy already calls for broadband infrastructure to be defined and planned for like any other public good such as roads, railways, oil pipeline, and power lines (MoICT&NG, 2018).

This paper aims to project the next generation wireless networks scenario of Uganda by 2025 when 5G connections are expected to have crossed the 1 billion mark globally. It builds upon an earlier scenario for Uganda's traffic profile by 2020 that focused on 3G and beyond (Okello *et al.*, 2015). The paper identifies major environmental constraints that current and future network architectures will face, in particular, with respect to deployment density and throughput requirements by year-end 2015 over a ten-year period to that forecast for 2025. The focus is on three services, namely, voice, mobile Internet and video that are currently among the highly utilized services among Ugandan mobile subscribers, and that are expected to have increasing throughput requirements over the period to 2025. The paper further compares the current and forecast traffic patterns of an urban and a rural area in Uganda.

3.0 TRAFFIC PROFILE IN UGANDA

Given the nature of investment required and the need for appropriate policy direction, it is important to map out Uganda's communications scenario for 2025. This includes analysis and specification of traffic requirements, the development and integration of new technical solutions, and the dissemination of results to ensure the required impact (Osseiran *et al.*, 2013). The focus of this paper is on the analysis and specification of Uganda's traffic requirements.

While one can assume that there will be traffic growth across the country, the rate is certain to differ between urban and rural areas. The urban-rural dimension is also important as operator intervention may be limited in rural areas due to poor returns on investment. For purposes of this work, Kampala District was selected as an urban area since it has a population density of over 1,000 persons/km^2, and Gulu District was selected as a rural area since it has a population density of under 300 persons/km^2 (Blume *et al.*, 2013). Gulu District is also considered a fast-growing area of interest for the telecommunication sector since Gulu

Municipality is among the top ten most populated municipals and towns in Uganda. These two districts were also the basis for the 2020 scenario study (Okello *et al.*, 2015). Table 1 presents a demographic profile of the two districts. It is assumed that the district land area remains the same over the period 2015 – 2025. The statistics for 2015 and the estimates for 2025 population statistics for Kampala, Gulu and Uganda are obtained from the Uganda Bureau of Statistics.

Table 1: Demographic profile of Kampala and Gulu Districts

	Area (km^2)	Population (2015)	Pop. density (2015, pop/km^2)	Population (2025, est.)	Pop. density (2025, pop/km^2)
Kampala	839	1,529,400	1,823	1,819,700	2,169
Gulu	3,449.08	282,000	82	370,300	107
Uganda	241,550.7	35,502,100	147	48,317,300	200

Source: Uganda Bureau of Standards (UBOS, 2019)

Typical of many Sub-Saharan African countries, Uganda's telecommunications needs are largely served by wireless and mobile networks (UCC, 2018). Furthermore, given the higher population density, it not surprising that the higher speeds of up to 21 Mbps are only available around Kampala (UCC, 2013).

4.0 ASSESSING UGANDA'S TRAFFIC REQUIREMENTS BY 2025

This paper focuses on Uganda's traffic requirements by 2025, particularly the throughput requirements. The throughput or data rate required for various services will in turn affect the technical solutions for provision of connectivity including the spectrum requirements. The projections are important to guide the growth mix requirement in infrastructure and policy to guide the path to the next generation wireless networks.

At the outset, it is important to acknowledge the difficulty in predicting capacity demands – more so, since different forecast studies provide varying results (Gelabert *et al.*, 2013). Nevertheless, for planning purposes, it is important to generate information on likely requirements. Secondly, as previously mentioned, a number of the traffic forecasts project exponential growth up to the order of 1,000 times growth. However, these forecasts are based on subscription and services trends in developed countries and may not be directly utilized for in the context of a developing country. Examples of these models include the GreenTouch framework applied in the most mature markets of North America, Western Europe and Japan (Blume *et al.*, 2013, Gelabert *et al.*, 2013); and use of historical, annual U.S. and global compound annual growth rates for traffic reported by a number of large carriers and industry analysts (Kilper *et al.*, 2011). Indeed the 2020 traffic forecast has been shown by today's trends to have about double the 25,211,164 subscribers by year-end 2017 (ITU, 2018a; Okello *et al.*, 2015).

For this work, the wireless traffic model used is by the Wireless World Research Forum (WWRF). This model is able to account for several demographic scenarios and user capacity estimates (Wu, J. *et al.*, 2011). The model accounts for the following environmental constraints: population density, penetration rates, user/subscriber density, energy constraints, and the regulatory environment. The WWRF model results tend to a conservative maximum ceiling since the model does not account for indoor/outdoor traffic as well as combined wireless/wired infrastructure (Gelabert *et al.*, 2013). Furthermore, in this work, the traffic requirements are estimated taking into account only population density, penetration rates, user/subscriber density and regulatory aspects. The user/subscriber density is obtained as a product of the population density and the penetration rates. Depending on the age structure of a population and the population aged above 15, there could be a saturation of penetration rates due to the actual number of wireless users/subscribers. With a very young population, even with a drop from 48 percent in 2015 to 43 percent in 2025 of those below the age of 15 (UBOS, 2019), the age structure is an important consideration for Uganda. Other factors that could affect saturation of penetration rates are literacy rates as well as accessibility and affordability of wireless services.

To assess the penetration rates over the period up to 2025, there is need to apply an appropriate trend for Uganda's traffic growth. Figure 1 compares different trend lines explored in the scenario 2020 study to estimate Uganda's traffic growth based on subscriber growth from 2000 – 2013 (Okello *et al.*, 2015).

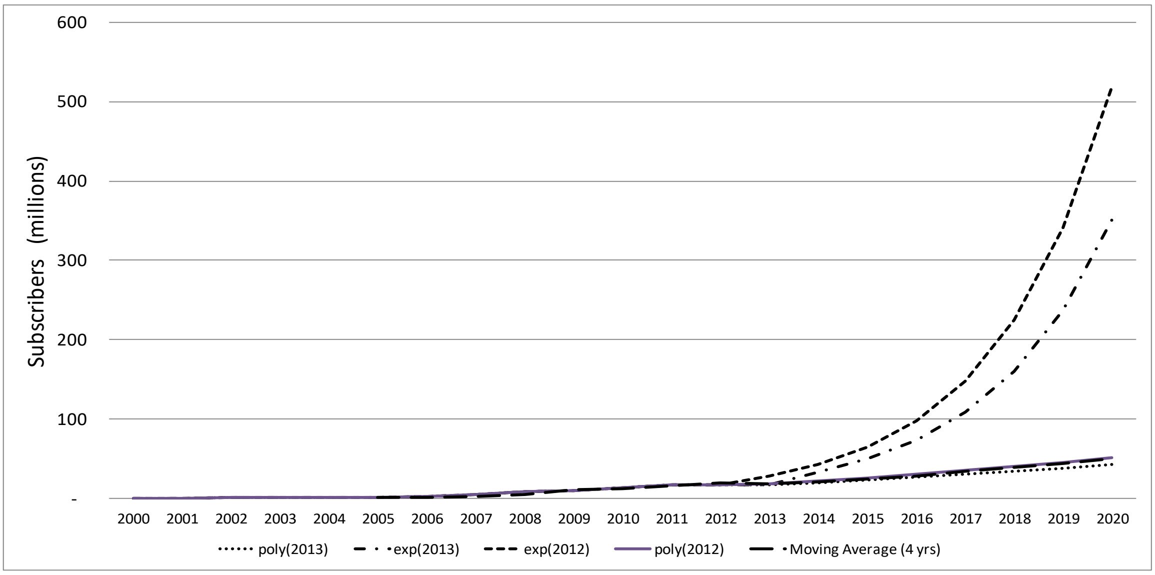

Figure 1: Possible trends of Uganda's subscriber growth up to 2020

Figure 1 compares different exponential and polynomial growth trend lines explored to estimate a best fit line to Uganda's traffic growth. While developed countries were considered to have exponential traffic growth (Blume, 2013), Figure 1 revealed that an exponential subscriber growth trend would result in unrealistic predictions for Uganda's subscribers by 2020. This is because it would mean that Uganda would achieve penetration saturation by 2014. Thus, a polynomial growth trend was selected to represent the trend of Uganda's subscriber growth, which in turn yielded the penetration rates of 0.48 and 0.95 in 2012 and 2020 respectively that were used in the 2020 study. However, these penetration rates are observed to have nearly doubled the estimate of Uganda's subscribers in 2020 relative to current statistics (UCC, 2018). For the scenario 2025 study, it is thus proposed to assume a conservative estimate of half the growth in penetration rate used for the year 2020. The user densities for the two regions under study are then obtained as highlighted in Table 2. A user density of at least 1,000 and 300 people per unit area (km) is required for classification of urban and suburban, respectively, with respect to telecommunications demand (Blume *et.al.*, 2013)

Table 2: User densities for Kampala District, Gulu District and Uganda

		Population Density (people/km^2)	User Density (people/km^2)	Classification
Kampala	2015	1,823	866	Suburban
	2025	2,169	1,030	Urban
Gulu	2015	82	39	Rural
	2025	107	51	Rural
Uganda	2015	147	70	Rural
	2025	200	95	Rural

Throughput Requirements for 2025

Throughput requirements for services per user, *T(s)*, introduced by a wireless service, *s*, may be estimated as a function of the bit rate requirement of each service, service usage rates, and user behavior according to the WWRF traffic model (Wu, J. *et al.*, 2011). Equation 1 estimates the throughput requirements for a user with multiple services.

$$T_{user} = \sum_{s=1}^{S} T(s) = \sum_{s=1}^{S} P_u(s)P_t(s)R(s) \quad (1)$$

where $P_u(s)$ is the percentage of users using service *s*, $P_t(s)$ is the probability that service *s* is used by wireless devices of a user at a given time and is a function of user behavior statistics and busy hour statistics, and *R(s)* is the bit rate required to deliver service *s* such as voice, data, video, etc.

While there are models that estimate the busy hour traffic by activity for mature markets such as Europe, no such models are in place for developing countries such as Uganda. Secondly, even for developed countries, it was very difficult to estimate $P_u(s)$, $P_t(s)$ and *R(s)* for all services in 2020 and this remains a challenge even for 2025. This is primarily because service statistics and user behavior are difficult to predict. To overcome the challenge for developing country predictions, the use of total traffic estimates per user has been proposed (Wu, 2011). These estimates can then be used to determine the throughput requirement per area, T_{area} – where T_{area} may be estimated as a product of the user density and throughput requirements per user.

To estimate Uganda's requirements, we use estimates reported by the Program for Infrastructure Development in Africa (PIDA, 2011). By 2018, it was expected that at least 10% of the population has high speed access, that 20 to 30% of the population has ready access to internet. For this study, we retain the same probabilities of access to the internet. For high speed access, we consider the average rates as proposed in the Uganda National Broadband Policy. Uganda's National Development Plan has envisaged broadband access speeds of 30 Mbps per household in urban areas, and the Broadband Policy requires at least 4 Mbps across the country (MoICT&NG, 2018). Table 3 presents the throughput requirements for Kampala and Gulu Districts based on application of the WWRF traffic model in which the use of total traffic estimates per user is applied.

Table 3: Throughput requirements for Kampala and Gulu Districts by 2025

	2025 (Mbps/km^2)	2025 (Mbps per capita)
	10% high speed (30 Mbps, Kampala), 30% good internet (4 Mbps)	
Kampala	4,120	2
Gulu	61.2	0.6

The 2025 results presented in Table 3 reveal significant requirements for Kampala relative to the requirements of Gulu. Furthermore, the throughput requirements were compared with those obtained by the PIDA study which forecast Uganda's bandwidth requirements by 2018 at about 600 Gbps (PIDA, 2011). It is observed that the 2025 requirement for Kampala exceeds the PIDA projection of 600 Gbps, while that for Gulu is below. This is not surprising as Kampala being a key urban centre would dominate the throughput requirements. However, it should be noted that forecasting based on extrapolation is typically problematic, and hence a limitation for this study. It is thus important to acknowledge that the results presented in this paper are indicative of the expected magnitudes of throughput required and are therefore treated as only estimates.

5.0 ANALYSIS OF RESULTS

Using Kampala and Gulu as samples of throughput requirements in Uganda, Table 2 shows a transition from sub-urban to urban status for Kampala while Gulu remains with a rural status with respect to telecommunications demand from 2015 to 2025. Still, there remains need for development of Uganda's national broadband infrastructure since even rural areas of Uganda will have increasing need for high-speed services. As reported in the National Broadband Policy, by September 2018, Uganda already had 45 percent 3G coverage. Secondly, the results obtained further point to two additional constraints that need to be addressed regulatory aspects and energy constraints. Increasing spread of infrastructure will have increasing energy requirements with wireless networks consuming up to 80% of the energy required for communication networks (Blume *et al.*, 2011, Kilper *et al.*, 2011, Zander *et al.*, 2013). While this study has focused on throughput requirements, it is important that further work take regulatory and energy constraints into consideration.

Furthermore, a key assessment for 5G services is available business cases for its deployment. While the National Broadband Policy calls for 4 Mbps across the country and the 4G and 5G standards provide for download speeds of 100 Mbps or more to be available on demand, the 2025 forecast shows a per capita requirement in Kampala of 2 Mbps. 5G tests show connection densities of 1 million devices/km^2 (Morgado *et. al.*, 2018) typically which may only occasionally be needed in Kampala for large events or high density of sensor networks. On the other hand, while 4G might not support dense deployments at massive industrial scale internet of things (IoT), it can support 2,000 connected devices/km^2 (Javaid *et. al.*, 2018) which can well serve the needs for Kampala. This means that adoption of 5G will require well considered business cases for its deployment. Today, a viable case can be made for 5G in densely populated urban areas (ITU, 2018). Viable use cases include high-speed mobile broadband to crowded areas, high-speed streaming for in-home services on demand, enterprise collaboration services, smart cities and IoT through massive deployment of low-power sensor networks in cities and in rural areas, low-latency applications such as remote surgery, factor automation and control of real-time processes, and last mile solutions in areas without fibre to the home connections or network backhaul solutions. 5G deployment in Uganda will therefore require an assessment for demand and/or a robust commercial case. Furthermore, this means that there is still need to retain the availability and quality of 4G networks as a viable broadband option as the case for 5G matures. There is also need for stimulation of nationwide deployment of fibre networks as well as affordable wireless networks so as to minimize the risk of increasing the digital divide arising from selected deployments of 5G networks. While the forecast in this study is focused on wireless networks, the National Broadband Policy requires that networks consider an appropriate mix of technologies to ensure efficient and complementary broadband infrastructure deployment nationwide. This means that an appropriate mix of wireless and wired/fiber options will need to be considered thus minimizing a risk that the digital divide in Uganda would increase because 5G networks were being prioritized over fiber networks, for example. The consideration of an appropriate mix is important since adoption of 5G is currently considered a viable option for densely populated urban areas whereas Uganda is largely rural as highlighted in Table 2.

In addition to the business case, a primary regulatory aspect is availability of spectrum to support increasing throughput requirements via wireless networks. For instance, of the five spectrum bands identified for 4G/LTE, the uplink spectrum range lies with the digital dividend expected to result from the digital migration process. However, while frequency re-allocation and dynamic spectrum access may provide rapid market entry possibilities, they will not be sufficient to make available the necessary spectrum for increasing throughput requirements (Zander *et al.*, 2013). There will also be need for techniques and enablers for innovative spectrum sharing and flexible spectrum management (Osseiran *et al.*, 2013).

As was the case for the 2020 study, another regulatory aspect to be addressed is multi-stakeholder collaboration through public-private partnerships, for example, to spur both rollout of infrastructure and motivation of demand for the infrastructure (Okello *et al.*, 2015). In terms of user density, Uganda is largely classified as a rural scenario and hence the need for innovative approaches to grow the country's telecommunications infrastructure and its usage.

6.0 CONCLUSION

Remarkable growth in the telecommunication sector is being witnessed in Uganda and beyond. Consequently, new networks are needed to service the growing demand. For Uganda, this growth shall largely be met by wireless networks but should be complemented by a right mix of technology including fibre networks. Future wireless networks could be deployed for future low latency and high reliability but also prevailing backhaul solutions due to high data rates of up to 100 Gbps. The design of Uganda's next generation wireless networks entails the need to assess future traffic requirements and major environmental constraints. The networks shall also entail a high degree of flexibility, efficient use of available radio resources and an energy-efficient operation at low operational costs.

Analysis of Uganda's 2025 traffic requirements reveals growth even with much of Uganda being classified as rural with low device/penetration density. Innovative technical and policy interventions will thus be required to support the traffic requirements. This shall include fostering public-private partnerships as well as development of innovative spectrum management techniques coupled with efficient energy management. At the foundation of these interventions is the need for further research focused on the regulatory and environmental constraints typical of developing countries such as Uganda.

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