Next-Generation Wireless Networks for Uganda 2020

Theme: Information and Communication Technology

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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 aims to project a next generation wireless networks scenario of Uganda by 2020. It identifies major environmental constraints that current and future network architectures will face, in particular in regards to deployment density and throughput requirements from 2012 to 2020. The paper further compares the current and forecast traffic patterns of Kampala District as an urban area and Gulu District as a rural but fast growing area. The WWRF wireless traffic model adopted projects 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 2020 showed a subscription growth to over 90%, and an almost five times increase in throughput. To meet future requirements with Uganda being largely rural by classification, there is need to foster public-private partnerships in addition to innovative spectrum management and efficient energy management.

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

1. INTRODUCTION

Since liberalization of the telecommunications sector, Uganda has witnessed remarkable growth in the sector. The GSM Association (GSMA) reports 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 has also created more than 3.5 million full-time equivalent jobs across both the formal and informal sectors.

The growth of demand in the telecommunication sector is expected to continue to grow even up to 2020, although at slightly slowing pace (Blume *et al.*., 2013). Studies conducted in developed countries have shown 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 is also expected that the current second generation (2G) and third generation (3G) wireless networks shall be replaced by fourth generation (4G) and beyond-4G networks (Blume *et al.*, 2013, Mogensen *et al.*, 2012).

In terms of services, growth is expected in five major categories, web, video, peer-to-peer, wireless data and wireless voice (Kilper *et al.*, 2011). These services represent only a fraction of the currently available or future services. In general, wireless and mobile Internet access are 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 per 100 persons which seems to be largely driven by a growth of mobile internet subscription (UCC, 2013). This growth is attributed, in part, to the growing popularity and usage of smart phones in Uganda. This also means a growth in demand for 3G 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). 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. They typically integrate use of technologies such as spectrum reframing/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.

This paper aims to project the next generation wireless networks scenario of Uganda by 2020. It identifies major environmental constraints that current and future network architectures will face, in particular in regards to deployment density and throughput requirements by 2020. In particular, the paper compares traffic patterns and throughput requirements by year-end 2012 to that forecast for 2020. 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 2020. The paper further compares the current and forecast traffic patterns of an urban and a rural area.

2. 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 2020. 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.

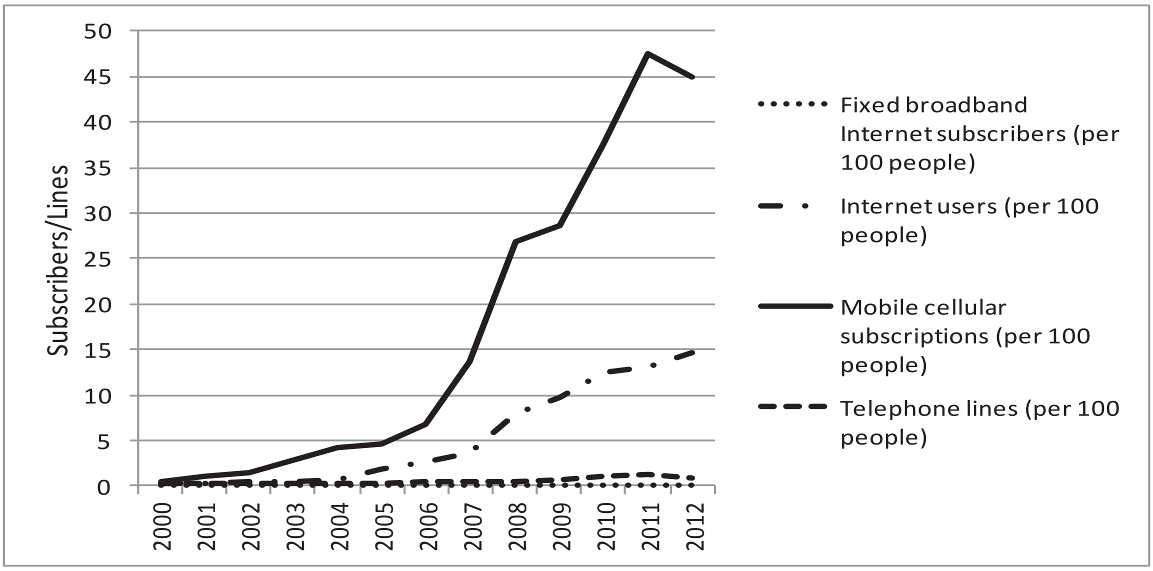
While one can assume that there will be traffic growth across the country, the rate is certain to differ between urban and rural areas. The urban-rural dimension is also important as operator intervention may be limited in rural areas due to poor returns on investment. As such, government intervention through public-private partnerships (PPP) may be required. For purposes of this work, Kampala District was selected as an urban area (with a population density of over 1,000 persons/km^2, Blume *et al.*, 2013) and Gulu District was selected as a rural area (with a population density of under 300 persons/km^2). 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. Table 1 presents a demographic profile of the two districts. It is assumed that the district land area remains the same over the period 2012 – 2020. Annual population growth rates of 3.4%, 2.8% and 3.2% from the Uganda Bureau of Statistics (2012) are used to estimate 2020 population statistics for Kampala, Gulu and Uganda respectively.

Table 1: Demographic profile of Kampala and Gulu Districts

	Area (km^2)	Population (2012)	Pop. density (2012, pop/km^2)	Population (2020, est.)	Pop. density (2020, pop/km^2)
Kampala	839	1,720,000	2,050	2,250,000	2,682
Gulu	3,449.08	396,500	115	494,525	143
Uganda	241,550.7	34,100,000	141	44,364,715	184

Source: Uganda Bureau of Standards (UBOS, 2012), Authors estimates for 2020

Typical of many Sub-Saharan African countries, Uganda's telecommunications needs are largely served by wireless and mobile networks. By 2011 year-end, the mobile internet subscriptions were more than four times the fixed internet connections (UCC, 2012). Furthermore, speeds of up to 21 Mbps were available on 3G and beyond networks but only around Kampala. Figure 1 highlights the growth in fixed and wireless services over the period 2000 – 2012.



Source: International Telecommunication Union (ITU)

Figure 1: Trends in fixed and wireless subscribers in Uganda, 2000 - 2012

3. ASSESSING UGANDA'S TRAFFIC REQUIREMENTS BY 2020

The objective of this paper is to assess Uganda's traffic requirements by 2020 with a focus on 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.

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).

For this work, the wireless traffic model used is by the Wireless World Research Forum (WWRF) that 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 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. 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 2020, there is need to apply an appropriate trend for Uganda's traffic growth. Figure 2 compares different trend lines for the period 2000 – 2020.explored to estimate Uganda's traffic growth. The trendlines were developed based on existing data on subscriber growth from 2000 – 2013 and investigation of different exponential and polynomial growth patterns for Uganda's traffic.

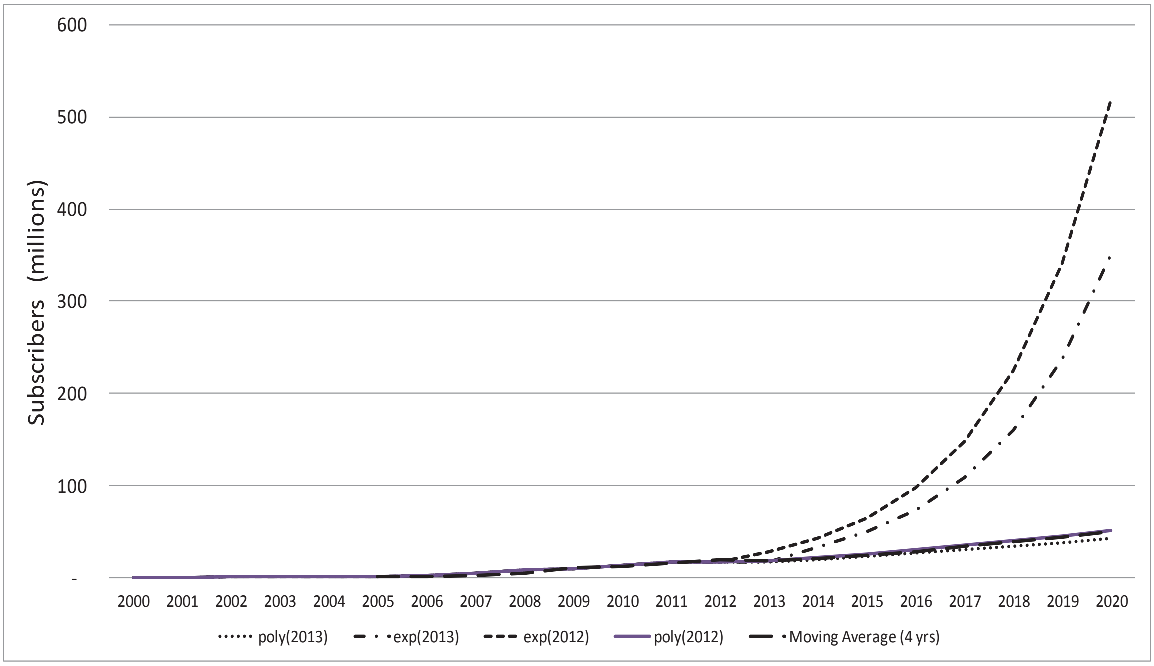


Figure 2: Possible trends of Uganda's subscriber growth up to 2020

From Figure 2, a conservative estimate of 42,147,920 was adopted to represent Uganda's subscribers in 2020. Figure 2 also reveals 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 shall achieve penetration saturation by 2014. The user densities are then obtained as highlighted in Table 2 for penetration rates of 0.48 and 0.95 in 2012 and 2020 respectively.

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

		Population Density (people/km^2)	User Density (people/km^2)	Classification
Kampala	2012	2,050	983	Suburban
	2020	2,682	2,548	Urban
Gulu	2012	115	55	Rural
	2020	143	136	Rural
Uganda	2012	141	68	Rural
	2020	184	174	Rural

3.1 Throughput Requirements for 2020

According to the WWRF traffic model, 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 (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 is very difficult to estimate $P_u(s)$, $P_t(s)$ and $R(s)$ for all services in 2020. This is primarily because service statistics and user behavior are difficult to predict. To overcome the challenge for developing country predictions, Wu, J. *et al.* (2011) propose the use of total traffic estimates per user. 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 is expected that at least 10% of the population has high speed access, that 20 to 30% of the population has ready access to internet, and that 120 Kbps of OnNet broadband (including 60 Kbps for international broadband) available per access. For high speed access, we consider the average rates for Africa projected by Cisco which are from 529 Kbps in 2013 to 1 Mbps in 2020 (Cisco, 2014). Table 3 presents the throughput requirements for Kampala and Gulu Districts.

Table 3: Throughput requirements for Kampala and Gulu Districts

	2012 (Mbps/km^2)	2020 (Mbps/km^2)	Growth Rate 2012 - 2020
	10% high speed (529 Kbps), 20% good internet (120 Kbps)	*10% high speed (1Mbps), 30% good internet (120 Kbps)*	
Kampala	75.6	346.5	4.6
Gulu	4.2	18.5	4.4

The PIDA study forecasts Uganda's bandwidth requirements by 2018 at about 600Gbps (PIDA, 2011). The 2020 results presented in Table 3 represent about 59% of Uganda's throughput requirements. Not surprising as Kampala being a key urban centre would dominate the throughput requirements. It is important to acknowledge that the figures presented in this paper are indicative of the expected magnitudes of throughput required and are not absolute values.

4. ANALYSIS OF RESULTS

Using Kampala and Gulu as samples of throughput requirements in Uganda, the results show at least a four-fold growth from 2012 to 2020 as highlighted in Table 3. This is also consistent with the expected growth in Africa of smart devices and connections having advanced computing and multimedia capabilities with a minimum of 3G connectivity (GSMA and Deloitte, 2012). These devices will have capabilities to carry various traffic include voice, data and video.

Table 4 highlights the need for development of Uganda's national broadband infrastructure since even rural areas of Uganda will have increasing need for high-speed services. 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). However, study of the energy constraint is outside the scope of this paper.

Table 4: Major Mobile Broadband Access in Uganda

	EDGE/GPRS	CDMA	3G+	WiMax	LTE (4G)
Coverage	Most areas with GSM phone coverage	Mostly around Kampala	Mostly around Kampala	Mostly around Kampala	Around Kampala and Entebbe
Maximum speeds supported	175 Kbps	Up to 3.5 Mbps	Up to 21 Mbps	3 Mbps	100 Mbps downlink and 50 Mbps uplink
Number of providers	4	3	4	1	3

Source: Uganda Communications Commission

The primary regulatory aspect is availability of spectrum to support increasing throughput requirements via wireless networks. For instance of the five spectrum bands identified for LTE, the uplink spectrum range lies with the digital dividend expected to result from the digital migration process. This process due to be completed by 2015 is reportedly behind schedule in Uganda. 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).

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. 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.

5. 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 as highlighted in Figure 1. 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 2020 traffic requirements reveals growth by over four times over the period 2012-2020 – even with much of Uganda being classified as rural. 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 environmental constraints typical of developing countries such as Uganda.

6. ACKNOWLEDGMENT

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Analysis of the Accuracy of GMF, NMF, and VMF1 Mapping Functions with GPT 50 a Priori Zenith Constraint in Tropospheric Delay Modelling

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Abstract
When modelling the tropospheric delay in Global Positioning System (GPS), the zenith delay is mapped to the slant with numerous mapping functions. The accuracy of the modelled tropospheric delay will be affected by the kind of mapping function used. Fixing the a priori zenith constraint as Global Temperature Pressure Humidity 50 (GPT 50), this paper compares the accuracy of the different mapping. Global Mapping Function (GMF), Niell Mapping Function (NMF) and Updated Vienna Mapping Function (VMF1), the update of Vienna Mapping Function (VMF) are the mapping functions studied. All these are used with the saastamoinen tropospheric delay model which is used in the GPS Analysis Software for the Massachusetts Institute of Technology software (GAMIT_GLOBK). For the north and east offsets these mapping functions achieved the same accuracy and can therefore be used interchangeably in modelling of the tropospheric delay effect in the planner. However, for the up offsets VMF1 achieved better accuracy compared to GMF and NMF however, being more consistent with GMF than NMF. In the future, if more mapping functions are incorporated in GAMIT_GLOBK, the accuracy of these new mapping functions should be investigated and use another a priori zenith constraint – meteorological data, which will improve positioning using Global Navigation Satellite System (GNSS).

Key words: GPT50, GPS, GMF, NMF, VMF1.

1.0 Introduction

Mapping functions of tropospheric delay models based on data from the numerical weather models have now been developed. Mapping functions use information about the vertical distribution of the refractivity therefore they can assess the thickness of the troposphere which is a basis for the determining of the value for the mapping function (Niell, 1996). Even though these mapping functions have been available for some years now, many analysts still use NMF because it depends only on the station latitude, height and the day of the year thus can be easily implemented in GPS software (Niell, 1996). However when NMF was compared withVMF1 it was discovered that it has deficiencies in the temporal behaviour and large static deficiencies in certain areas. Therefore GMF was developed similar to NMF as it is determined from the station latitude, height and day of the year. However GMF is based on spherical harmonics up to degree and order 9 and the aim is to make it more consistent with VMF1 than NMF. Boehm et al. (2006a) used the rigorous ray trace at 3^0 elevation to determine VMF1. VMF1 is available on a 2.5 X 2.0 degree grid with a grid of 0.25x0.20 degree at some places at a temporal resolution of 6hours with planned reduction in this temporal resolution. GMF and NMF have larger standard deviations because they contain only a seasonal term and thus cannot reproduce the short-term variations sampled by VMF1