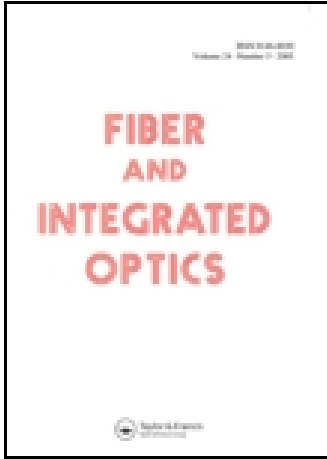


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T. Bulega<sup>a</sup>, A. Kyeyune<sup>a</sup>, P. Onek<sup>a</sup>, R. Sseguya<sup>a</sup>, D. Mbabazi<sup>a</sup> & E. Katwiremu<sup>a</sup>

<sup>a</sup> Department of Networks, Makerere University, Kampala, Uganda  
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# Uganda's National Transmission Backbone Infrastructure Project: Technical Challenges and the Way Forward

T. BULEGA,<sup>1</sup> A. KYEYUNE,<sup>1</sup> P. ONEK,<sup>1</sup> R. SSEGUYA,<sup>1</sup>  
D. MBABAZI,<sup>1</sup> and E. KATWIREMU<sup>1</sup>

<sup>1</sup>Department of Networks, Makerere University, Kampala, Uganda

**Abstract** Several publications have identified technical challenges facing Uganda's National Transmission Backbone Infrastructure project. This research addresses the technical limitations of the National Transmission Backbone Infrastructure project, evaluates the goals of the project, and compares the results against the technical capability of the backbone. The findings of the study indicate a bandwidth deficit, which will be addressed by using dense wave division multiplexing repeaters, leasing bandwidth from private companies. Microwave links for redundancy, a Network Operation Center for operation and maintenance, and deployment of wireless interoperability for microwave access as a last-mile solution are also suggested.

**Keywords** transmission backbone, bandwidth, broadband, last-mile solution, wireless interoperability for microwave access

## 1. Introduction

The National Transmission Backbone Infrastructure (NTBI) project aims at providing broadband services to government ministries, universities, schools, health centers, administrative headquarters, and private-sector entities in Uganda, as well as backhauling regional traffic from neighboring countries to the sea cable [1]. As discussed in [2], the NTBI project is Uganda's lubricant for achieving the Millennium Development Goals (MDGs) by stimulating employment, economic growth, and social development.

This project is being implemented by a Chinese company, Huawei Technologies, contracted by the government of Uganda. However, studies done in [3, 4] highlighted a number of challenges facing the NTBI project. The challenges include capacity and footprint limitations as well as high project cost and project management difficulties, as explained in what follows.

### *Limited Bandwidth Due to the Cable Type Installed*

The cable type installed in the NTBI project is the G652 fiber-optic cable. This cable, according to research studies in [1], has some challenges that can compromise the performance of the cable. The challenges include four-wavelength mixing (FWM), high

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Address correspondence to Dr. Tonny Bulega, Department of Networks, Makerere University, P.O. Box 7062, Kampala, 256, Uganda. E-mail: tbulega@cit.mak.ac.ug

**Table 1**  
Optical characteristics of G655 and G652 [5]

Optical characteristics	G655	G652
Attenuation at 1,550 nm (dB/km)	$\leq 0.25$	$\leq 0.25$
Dispersion at 1,530 nm to 1,625 nm (ps/nm/km)	1–14	14–23
Dispersion slope (Ps/km/nm <sup>2</sup> )	$\leq 0.07$	$\leq 0.09$
Effective area ( $\mu\text{m}^2$ )	55	80
Mode field diameter ( $\mu\text{m}$ )	8.3–9.7	10.1–10.9
Channel spacing (nm)	$\leq 0.8$	$\leq 0.8$

levels of chromatic dispersion, and a low dispersion distance. The G652 cable can only transmit 2.5 Gbps but is upgradable to 40 Gbps using wavelength division multiplexing (WDM). This is incomparable to the G655 which has an initial capacity of 40 Gbps. Stakeholders believe that the capacity limitation will stifle running projects like e-health or e-education using video-links, because they require huge bandwidth. For instance, Makerere University (Kampala, Uganda) had planned to establish five up-country centers allowing students to attend classes at the main campus through a video-link. The dispersion distance of the G652 is 70 km in contrast to that of the G655 cable, which is over 210 km. When using WDM, there is a trade-off between dispersion distance and the bandwidth of a fiber-optic cable. A G652 fiber-optic cable, for example, can have 2.5-Gbps capacity with a dispersion distance of 1,000 km, 10-Gbps capacity with a dispersion distance of 60 km, and 40-Gbps capacity with 3-km dispersion distance.

#### *Small Number of Cores of the Fiber-Optic Cable*

The G652 cable being laid is a 24-core fiber cable, compared to the G655 cable with 96 cores. The number of cores determines the number of separate channels. Security sensitive information, for example, is preferably transmitted through a separate channel. The advantage of more cores is their ability to be distributed over a much wider area.

In some instances, the cores not used by the designated national users could be leased to third-party providers, making it a profitable business. Some of the optical characteristics of G652 and G655 cable types as specified by the International Telecommunications Union (ITU) are summarized in Table 1, and the performance parameters are shown in Table 2.

**Table 2**  
Network performance parameters of  
G652 and G655 [5]

Network parameters	G655	G652
Number of channels	160	80
Bit rate (Gbps)	2.5–10	2.5
Bandwidth per fiber (Tbps)	1.6	0.2
Reachable distance (km)	210	70

### ***Limited Footprint of the Backbone Infrastructure***

The fiber-optic cable will only link Kampala City to 20 other cities. This raises a question of how the remaining 92, out of 113 districts, will access the broadband services. For instance, it was pointed out in [6] that the Karamoja and West Nile regions will not benefit from the NTBI project. In the rest of the uncovered districts, there are institutions, such as primary schools, secondary schools, health centers, and administrative headquarters, that need broadband services.

### ***Limited Upgradability and Lack of Future Proof for the Backbone Infrastructure***

The installation of the fiber-optic cable will stimulate the use of broadband services and traffic growth. Subsequently, the growth in traffic is likely to pose constraints on the capacity of the backbone infrastructure, which cannot be expanded in a timely manner.

### ***Operation and Maintenance of the Infrastructure***

The NTBI project was meant to install the Network Operation Center (NOC) in Phase 2. However, Phase 1 is already in use without an NOC. This raises questions of how configuration management, fault management, and minor upgrades of the backbone infrastructure are being done.

### ***Project Cost***

In addition to the aforementioned technical issues, experts as well as previous studies [1] have raised concerns about the cost of deployment of the fiber-optic backbone. From Table 3, it can be seen that Uganda is spending a lot more money than Rwanda, Afghanistan, Angola, and Cameroon to implement the NTBI project [1, 6–9].

### ***The Challenge of Project Management***

In [1], it was pointed out that the Project Implementation Unit (PIU) is understaffed to supervise the contractors. This jeopardizes the quality of work and introduces a future vulnerability of the network since some poorly installed parts can easily fail.

Previous studies [3] have modeled the national and international bandwidth requirements of the NTBI project and demonstrated that there is a capacity gap between the installed and the desired bandwidth. Related studies [1] have identified similar

**Table 3**  
NBI project cost for different countries

Country	Cable length (km)	Cost (million US\$)
Uganda	2,100	106
Rwanda	2,300	38
Afghanistan	3,200	64.5
Angola	8,000	160
Cameroon	5,600	163.3

challenges and recommended a full technical audit of the NTBI project. The question of operation and maintenance, especially the risk of fiber cuts, was also highlighted in [6]. The remedy proposed for fiber cuts was harmonization of excavation works. However, this remedy does not cater to cases of fiber cuts that occur by mistake. A fourth phase to lay fiber-optic cable to areas left out in Phases 1, 2, and 3, such as the Karamoja and West Nile regions, is suggested. However, this will necessitate a lot more money than the use of a wireless last-mile solution.

This research revisits the traffic model in [3] and, using additional assumptions, forecasts a five-year national and international bandwidth requirement. It then suggests new techniques of enhancing the capacity of the fiber-optic cable taking advantage of WDM technology. In addition, the research proposes the commissioning of an NOC. Finally, the research proposes the installation of wireless interoperability for microwave access (WiMAX) base stations as a last-mile solution.

## 2. Background

The government of the Republic of Uganda, as part of the strategic programs to achieve the MDGs, decided to set up an NTBI using fiber-optic cable. Fiber-optic cable was selected among several transmission media due to its advantages, such as its ability to support higher data rates; error-free transmission over long distances; ease of handling, installing, and testing; and long-term economic benefits [10–12]. The Uganda Government took advantage of a concessionary loan provided by the government of the People's Republic of China through the Chinese Export and Import (EXIM) bank to initiate two enabling priorities—the establishment of the e-government infrastructure (EGI) and the national data transmission backbone infrastructure (NDTBI)—as part of a project that was to be run by a Chinese company, Huawei Technologies [13].

A task team was consequently established by the Ministry of Information and Communication Technology (ICT) in order to provide the government with recommendations on the policy, legal, and regulatory environment and the necessary changes thereto; enable EGI and NTBI; formulate national requirements and work with the contractor in fully defining and costing the initiatives; and carry out a feasibility analysis of the initiatives and make recommendations on governance and operations during and after the project phase. It should be noted that the consideration of major information systems that requires a different approach was not a component of the terms of reference of the task team. The urgency of getting the project formally started was, however, underscored; the efficiency gains from the major investment in the EGI would not be realized until the high-level information systems become operational.

The contributions made by the task team included contextualizing the project (i.e., examining various key documents, including the Constitution, Draft Vision 2035, Poverty Eradication Action Plan [PEAP], National ICT Policy, Proposed New Telecommunications Sector Policy, Proposed National Information Technology Authority–Uganda bill, broadcasting policy, MDGs, and related recommended strategies) and demonstrating the need and justification for both EGI and NTBI. The task team also came up with a project feasibility or business model for the project, showing revenue generation for servicing the loan and showing how profits would be generated; made some amendments in the technical specifications of the project, such as the physical location of the installations and introduction of rings, to cater for scalability, modularity, and future proof; and finally, suggested a project management and implementation master plan as well as the operational phase governance structure. However, time constraints did not allow

amendments of most of the technical specifications, such as the cable type and the method of laying the cable underground.

The NDTBI and e-government project was designed with two main components namely, the NDTBI and the EGI. The NTBI involves the establishment of a new stand-alone network, independent of the existing infrastructure. The scope of the NTBI encompasses laying 2,100 km of optic-fiber cables, together with the switching equipment and network infrastructure. The EGI component, on the other hand, is designed to improve communications between government agencies and the delivery of e-government services.

The backbone infrastructure is very instrumental for Uganda's development. The high-speed broadband infrastructure will spur high-speed internet connectivity all over the country and, thus, facilitate the achievement of the development objectives interpreted under business process outsourcing (BPO) and the telecom policy. This positions Uganda as a regional ICT hub and a country of choice for BPO, connecting all schools, health centers, agricultural extension work, research stations, major towns, and business centers by 2013. This infrastructure ultimately was meant to be linked to the submarine cables that have recently arrived at the east African coast, as shown in Figure 1, and provide faster and cheaper internet access to Uganda [14].

The NDTBI and e-government project is a three-phase project, estimated to cost US\$127 million [6]. The first phase, estimated at a cost of US\$30 million, involved the laying of 168 km of fiber-optic cable to link the towns of Mukono, Bombo, Entebbe, and Jinja to Kampala. This phase has been completed and has achieved some of the planned deliverables, such as interconnecting 27 ministries and some government departments like the police, army, and prisons at 30 sites within Kampala, Mukono, Bombo, Jinja, and

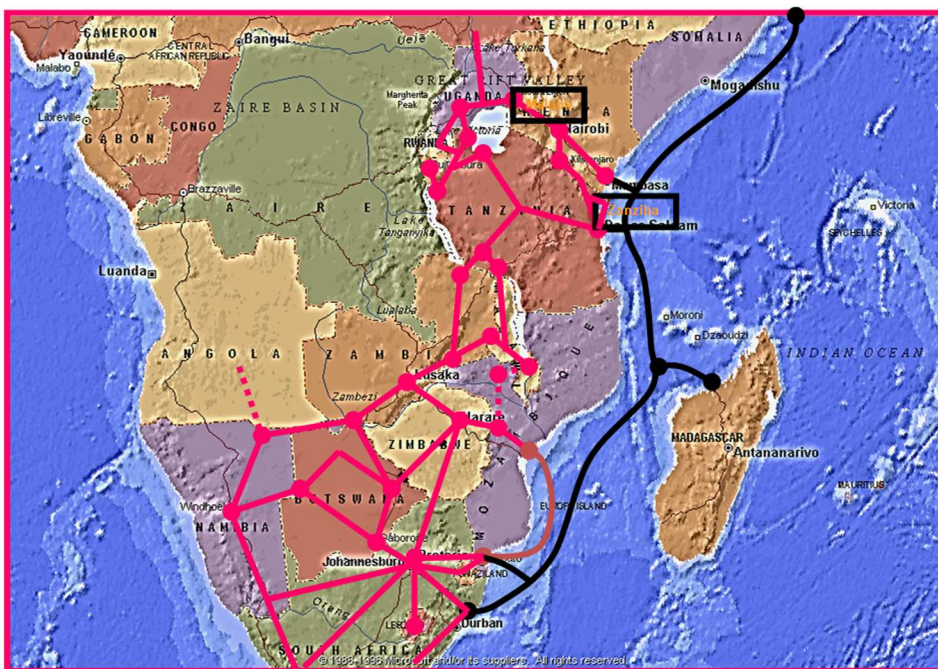


Figure 1. Backhaul links to EASSy cable [15]. (color figure available online)

Entebbe, as well as delivery and installation of communication equipment to the 30 sites, which form part of the e-government network and deploying video conferencing facilities to all the ministries and government departments mentioned [6]. The network architecture is shown in Figure 2.

Phase 2 of the NTBI component of the NDTBI project was scheduled to commence in financial year 2008–2009, and it involves laying fiber-optic cable to link the towns of Iganga, Bugiri, Busia, Tororo, Mbale, Kumi, Soroti, Lira, Gulu, Masindi, Hoima, Kyenjojo, Fortportal, Kasese, Bushenyi, Mbarara, Ntungamo Kabale, Katuna, Luwero, and Nakasongola, as well as building an NOC together with a modern internet exchange point (IXP) [6].

Phase 3 involves the laying of the cable to connect the towns along Kampala, Mpigi, Masaka, Lyantonde, and along the Mbarara highway to complete the link, as well as connecting all borders of Uganda to ensure optimum use of all international cables at Busia and Nimule. Specific goals of Phase 3 include rolling out a voice network across all government offices utilizing the voice-over-internet protocol (VoIP) solution and routing of internet traffic through a common internet gateway at the Uganda Communications Commission (UCC) offices. Other goals include expanding the government network to 16 other towns besides Kampala, Jinja, and Entebbe, thereby creating metropolitan area networks (MANs) within the towns and a wide-area network (WAN) across the national backbone, development of a primary data center for all government data at National Information Technology Authority of Uganda (NITA-U) offices, Statistics House. The data center would comprise of a data bank that would house the web portal, e-mail, storage, security, and office automation servers. In addition, Phase 3 would deliver the deployment of a secondary data center in Jinja to act as a disaster recovery site (DRS) for government data and deployment of e-mail services centrally at a base site in the Statistics House [6].

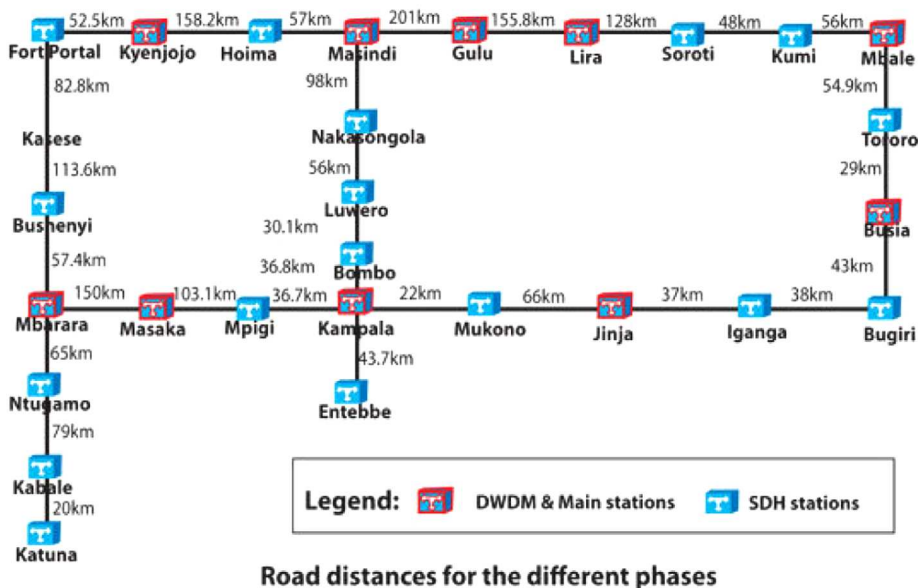


Figure 2. NTBI architecture [1]. (color figure available online)

### 3. Analysis of Uganda's Bandwidth Requirements

In [3], Uganda's internet connectivity requirements were quantified as coming from connectivity for public and private institutions, which, at the moment, is predominantly narrow band. The primary focus of the government was to address the needs in the public sector, especially the needs of educational institutions and health facilities. This study analyzed and modeled the bandwidth requirement that should be made available for the NTBI project to achieve its goals.

The modeling was performed based on historical data gathered from related literature and forecast data obtained by making some assumptions, such as taking only 1% of the subscribed users or registered users connected to the network simultaneously; that is, the default contention ratio of 1:100 was used. Based on studies in [16], the bandwidth requirement per user for broadband services, such as fast web browsing, video-conferencing, telemedicine, and distance learning services, was considered to be 256 Kbps. This assumption differs from that made in [3] that the bandwidth required per connection would double annually, from 256 Kbps in Year 1 to 512 Kbps in Year 2, and so on.

In developing the model, the following mathematical notations were used:

$B_{req}$  is the national bandwidth requirement per annum,

$B_{use}$  is the national bandwidth usage per annum,

$P$  is the national population,

$p_i$  is the population per institution,

$p_t$  is the total population for all institutions,

$p_u$  is the simultaneously connected users (%),

$b_u$  is the bandwidth requirement per user, and

$c$  is the number of connections.

The bandwidth requirement and usage were computed using Eqs. (1) and (2), respectively:

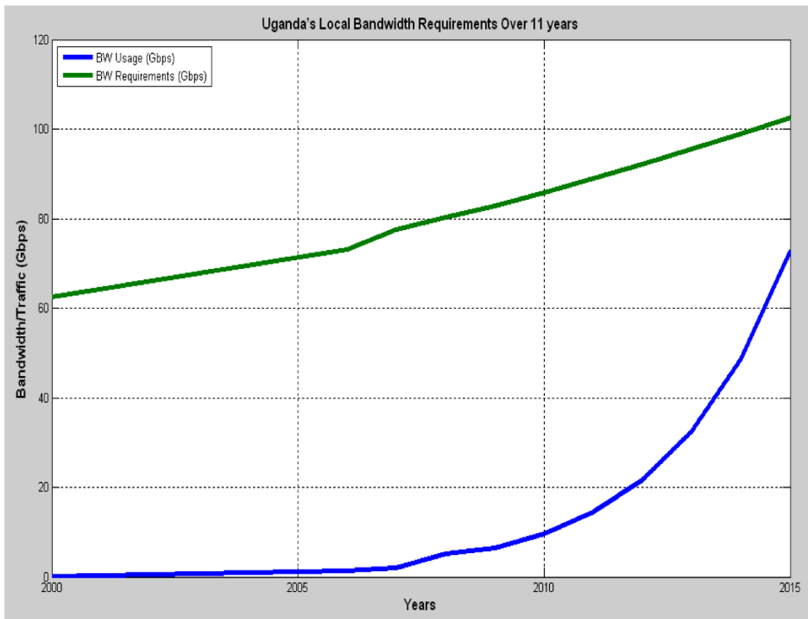
$$B_{req} = \frac{P * \left( \frac{p_i}{p_t} \right) * p_u * b_u}{10^6}, \quad (1)$$

$$B_{use} = \frac{p_u * c * b_u}{10^6}, \quad (2)$$

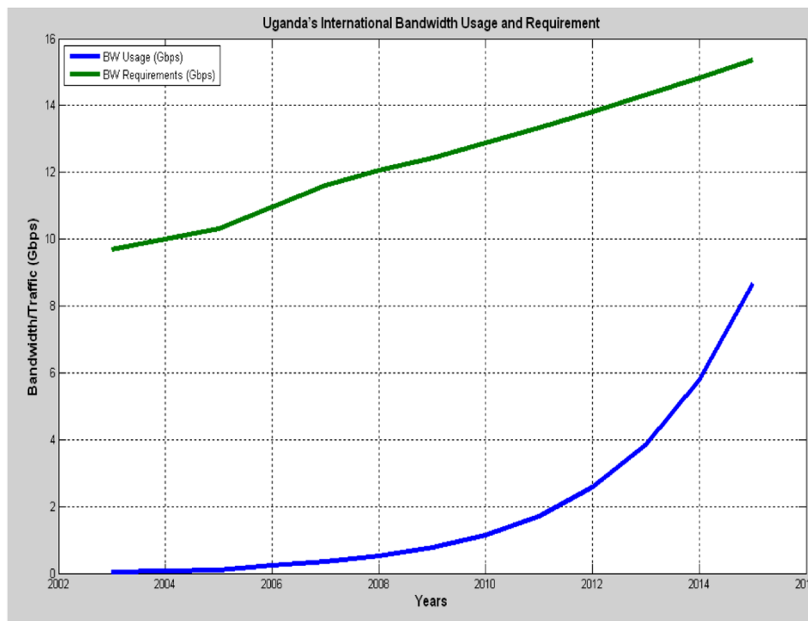
taken to be 3.6% per annum, as indicated in [17], and the growth in internet connectivity penetration is taken to be 25.5% per annum [18]. Seventy percent of the traffic was assumed to be originating from Kampala metropolitan area, and 30% of the traffic was assumed to be originating from areas outside Kampala. With the aforementioned assumptions and using Eqs. (1) and (2), input data obtained from related studies [3, 5] were extrapolated. The national bandwidth demand was modeled, and the bandwidth usage and requirements were plotted over time, as shown in Figure 3.

To drive bandwidth usage to match the ideal bandwidth requirement shown in Figure 3, there is need for a deliberate effort by the government to increase internet usage through subsidization of internet tariffs, as connection to the East African Submarine Cable System (EASSy) will bring down international bandwidth costs.

To consider the percentage of connections that are routed internationally, data from [3] was extrapolated using the preceding assumptions and Nielsen's law. The international bandwidth requirements and usage obtained was then plotted against time, as shown in Figure 4.



**Figure 3.** Uganda's national bandwidth usage and requirement from 2000 to 2015. (color figure available online)



**Figure 4.** International bandwidth usage and requirement. (color figure available online)

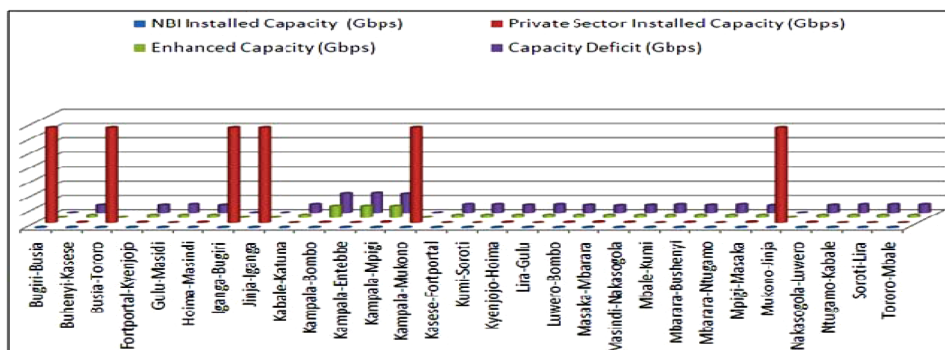
The capacity of the fiber-optic cable network being laid in the NTBI project is 2.5 Gbps. When compared with the bandwidth usage and requirement of Figures 3 and 4, it is evident that the NTBI project will not deliver the bandwidth requirements of Uganda. It is therefore pertinent that enhancements are made to the fiber-optic cable to increase its bandwidth or swap the G652 cable with a better fiber-optic cable type, such as the G655 cable. The latter option is very costly given the shortage of funds. The former option can be addressed using the alternatives explained in the next section.

#### 4. Suggested Way Forward

The results of the analysis and modeling done in the preceding section provides evidence of the deficit in bandwidth required by an aggregation of the demand by all institutions and users who will benefit from the services running on the transmission backbone. The challenges presented by previous studies have also been confirmed in the preceding sections. This section suggests solutions to the various challenges as explained hereunder.

##### *Use of Dense Wave Division Multiplexing (DWDM) Repeaters after Shorter Distance*

Using DWDM repeaters will increase the capacity of the cable and fill the deficit identified in Section 3. A G652 fiber-optic cable can have 2.5-Gbps capacity when repeaters are placed after 1,000 km, 10-Gbps capacity when repeaters are placed after 60 km, and 10-Gbps capacity when repeaters are placed after every 3 km. The use of repeaters after 3 km is proposed in Kampala City to increase the capacity of the cable from 2.5 Gbps to 40 Gbps. This follows the assumption that 70% of the traffic will be generated from Kampala, and the rest will originate from areas outside Kampala. Also proposed is the use of repeaters after 60 km in areas outside Kampala to increase the capacity of the cable from 2.5 Gbps to 10 Gbps. By 2015, the bandwidth requirement for the links serving the Kampala metropolitan area will be 71.7 Kbps and 30.7 Kbps for links serving the rural towns, as shown in Figure 5. However, the current installed capacity is 2.5 Gbps for links serving Kampala and the rural areas.



**Figure 5.** Installed, enhanced, and deficit capacity per NTBI link (Gbps). (color figure available online)

Figure 5 shows that there is a deficit capacity requirement for all links. The installation of 217 DWDM repeaters is therefore suggested to enhance the capacity of the various links.

### ***Installation of Fiber Cables over Power Lines***

Studies in [19] have indicated that the installation of fiber-optic cable power lines in Bangladesh was found to be 40% less expensive than using the trenching method. Therefore, the use of overhead or power line fiber-optic installation is suggested for Phases 2 and 3 of the NTBI project to cut down costs and time. This will also lead to better availability, as the cable will not be prone to mechanical cuts caused by road construction works and sewage system installations. The method of installing fiber on power lines is already being used by some telecom operators, such as MTN Uganda.

### ***Leasing of Bandwidth from Private Companies***

Bandwidth can be leased from the private telecom companies to supplement the bandwidth owned by the government. Telecom companies, like MTN and Uganda Telecom, can, for example, supply bandwidth to route traffic to Rwanda and Sudan, since those countries could afford to cover the interconnect costs. Figure 5 shows capacity installed by the private sector.

### ***Implementing Redundancy***

Though the architecture of the NTBI network has two rings, there is a need to use some wireless back up, such as a microwave. This can be done cost effectively by sharing towers with the private telecom companies. A microwave link costs about US\$20,000. Ten links can implement sufficient redundancy and can be installed for about US\$200,000.

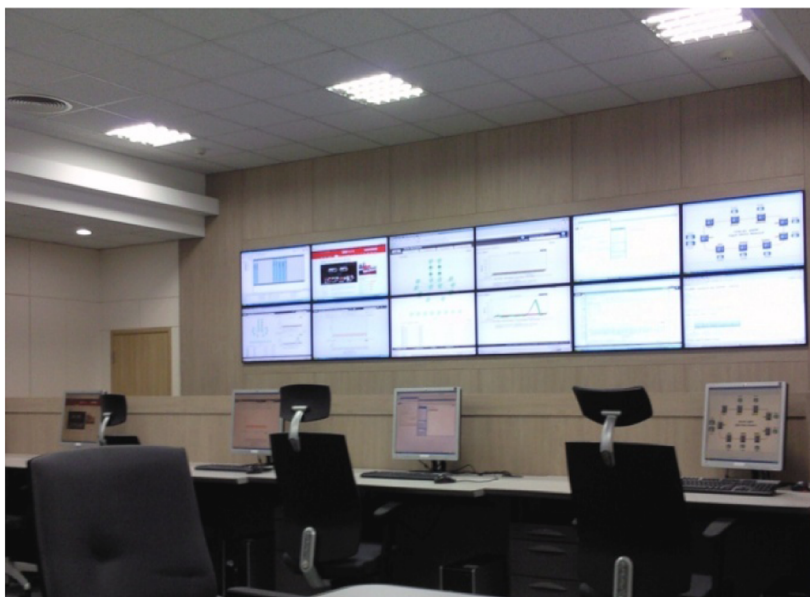
### ***Setting up an NOC***

An NOC, like the one shown in Figure 6, needs to be set up to enhance monitoring and operation of the network. Some tasks that will be done by the NOC include configuration of capacity for different customers, repair and maintenance, as well as fault handling of occurrences of node faults and fiber cuts.

### ***Extend the Broadband Coverage Using WiMAX***

Despite the fact that the NTBI project is meant to benefit different institutions, the backbone only connects major towns and cities. To realize the strategic goals of the project and its vision, the infrastructure must be extended to the rural locations using an additional topological layer or segment of the network to spur it from the backbone to the users.

Related studies in [3, 19] have suggested the use of WiMAX as a broadband technology, to extend the footprint of the national backbone to remote areas that are not considered in the present design of the NTBI network. WiMAX has been successfully used to provide access for hard-to-reach areas, such as rural locations, places with



**Figure 6.** Rwanda's NOC at Telecom House for real-time network control and monitoring [9]. (color figure available online)

rugged terrain and scarce energy, as well as areas with limited resources for technology deployment.

The use of WiMAX will enhance a number of important services, such as security services using video surveillance, educational centers sharing important information over a network with high-speed connections, healthcare services (such as giving patients, medical staff, and administration employees the ability to have internet and intranet access), as well as public safety services that involve all users and devices attaching directly to the wireless backbone and seamlessly integrating with networks inside buildings, police, and fire vehicles.

## 5. Conclusion and Recommendations

This research investigated the technical challenges facing Uganda's NTBI project. The challenges raised relate to the technological capability, financial prudence, and implementation of the project. The analyses done by previous studies were revisited, and with the help of new assumptions, a model of the bandwidth requirement was constructed. The research suggested ways of addressing the challenges of the NTBI project using alternatives such as the use of DWDM, leasing bandwidth from private companies, the use of microwave links for redundancy, setting up an NOC for operation and maintenance, and deploying WiMAX as a last-mile solution.

It is recommended that the G652 either be swapped to the G655 cable or that a more cost-effective interim solution using the aforementioned suggestions be deployed to ensure success of the currently struggling project. If this is done, Uganda will still be on course to benefit from an essential ICT infrastructure to gear the country toward achieving the MDGs.

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## Biographies

**Tonny Eddie Bulega** was born in Kampala, Uganda, in 1975. He received his Ph.D. and M.Sc. in telecommunication and information engineering from South China University of Technology, Guangzhou, China, in December 2008. He received his B.Sc.Eng. from Makerere University in 2000. He also received the distinguished international students' scholarship award from the Ministry of Education of China. During his stay in China, he was affiliated with the Guangdong Institute of Telecommunication Research and Huawei Technologies. He is currently a lecturer of Mobile Communication Engineering at Makerere University. His research has spanned a large number of disciplines emphasizing communication system principles. He is currently the head of the wireless sensor networks group at Makerere, formulating solutions relevant to the national development plan. He is a member of the International Engineering Consortium.

**Apolo Kyeyune** holds a B.Sc. (electrical engineering) and an M.Sc. (electrical engineering) from Makerere University, Kampala, Uganda, a postgraduate diploma (monitoring and evaluation) from Stellenbosch University (RSA), and a master of philosophy–social science methods (monitoring and evaluation) from Stellenbosch University (RSA). He has worked with Makerere University for the last ten years, initially as an academician and later as an ICT professional. He has been at the helm of designing and implementing the integration of ICT within the university functions over the last eight years. During this time, he has built skills in project design, management, implementation, monitoring, and evaluation. He has a wealth of experience in ICT policy development, strategic planning, infrastructure design, and project management, and he has a passion for effective service delivery and support that is customer oriented. He is also an M&E expert with a wealth of knowledge and skills in the conception, design, and implementation of evaluation activities. He has carried out a number of program evaluation studies spanning different fields. Through his M&E training, he has acquired a wealth of skills in the methodologies of social research, both qualitative and quantitative.

**Paul Onek** was born in Kitgum, Uganda, in 1979. He received a first-class honors B.Sc. (electrical engineering) in 2004 from Makerere University, Kampala, Uganda. He has submitted his dissertation for the award of a master of science in data communication and software engineering of Makerere University, Kampala, Uganda. He was a teaching assistant in the Department of Electrical Engineering, Makerere University (2004), where he taught engineering mathematics, microprocessors, and introduction to computers. He is a principal radio planning and optimization engineer at MTN Uganda, a company he joined in 2004. At MTN, he has gained experience in designing and optimizing several wireless networks, like GSM, CDMA, WiMAX, and UMTS. His research interests are in quality of service optimization in cellular networks.

**Ronald Sseguya** was born in Nsambya, Uganda, in 1979. He received a second-class honors bachelor of science in computer science in 2007 from Makerere University, Kampala, Uganda. He is currently working toward his masters in data communication

and software engineering at Makerere University, Kampala, Uganda. In 2006, he joined Uganda Clays Ltd, Kajjansi, as an information technology assistant. He is currently working as a statistician with Uganda Clays Ltd, Kajjansi, Kampala, Uganda. He has co-authored a paper, "The Feasibility of National Roaming in Highly Competitive Mobile Markets. A Case Study of Uganda," to be presented in the 7th Annual International Conference on Computing and ICT Research (ICCIR'11) from 7–9 August 2011 in Kampala, Uganda. His research area is quality of service (QoS) in telemedicine networks.

**Denis Mbabazi** was born in Hoima, Uganda, in 1975. He received a diploma in electrical and electronic engineering in 2000 from Uganda Polytechnic, Kyambogo, and a second-class honors bachelor of science in computer science in 2007 from Makerere University, Kampala, Uganda. He is currently working on a project that is the last requirement for a master in data communication and software engineering at Makerere University, Kampala, Uganda. He was a technician in Uganda Electricity Board (UEB) in 2000, where he gained experience in power installations, and a technician in Shell Uganda in 2001, gaining experience in electronics. He was a technician at the Directorate of Information and Communication Technology Service, Makerere University (2002–2005), where he was part of the team that set up the fiber backbone infrastructure and firewalls in the university for student research. He is now a network administrator with the university in charge of designing, maintaining, and managing networks and systems.

**Egrance Katwiremu** was born in Sheema, Uganda, in 1953. She received a diploma in education from Makerere University, Kampala, in 1975, a bachelor of humanities (aegrotat) degree from University of London in 1981, a postgraduate diploma in statistics in 1990, and a postgraduate diploma in computer science in 2006 from Makerere University. She is currently pursuing a master of science in information systems of Makerere University, Kampala, Uganda. She was head of Mathematics Department at Bweranyangi Girls' Secondary School, Jinja Senior Secondary School, and City High School Kampala, Uganda, between 1975 and 1989. From 1991 to date, she has been a systems analyst at Uganda National Examinations Board, where she has developed examination processing software and taught computer applications to staff. She is now a senior systems analyst.