Uganda's National Transmission Backbone Infrastructure Project: Technical Challenges and Way Forward

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Abstract- **Several publications such as media articles have pointed out key technical challenges facing Uganda's National Transmission Backbone Infrastructure (NBI) project. The challenges emanate from the use of G652 instead of other fiber-optic cable types like the G655 fiber-optic cable. However, the articles do not suggest ways of addressing the technical limitations of the project. This paper uses an exploratory, quantitative and analytical approach to evaluate the goals of the project, and the already deployed part of the infrastructure, and compares the evaluation results, against the technical capability of the backbone, based on global backbone infrastructure performance benchmarks. A survey of previous work and results from related studies form inputs to a grounded theory-based hypothesis formulation. The paper highlights the national demand of bandwidth by all anticipated users such as government ministries, universities, schools, health centers, administrative headquarters and private sector entities. The findings of the study are validated through comparisons with results of investigations carried out on similar projects in developing countries. Finally the paper suggests ways of addressing the challenges of the NBI project using alternatives such as the use of Dense Wave Division Multiplexing (DWDM) repeaters after shorter distances, leasing bandwidth from private companies to cater for the deficit, use of microwave links for redundancy, setting up a Network Operation Center (NOC) for operation and maintenance, and deployment of WiMAX as a last mile solution.**

Keywords
Transmission backbone, Broadband, Last mile solution, Bandwidth, WiMAX

I. INTRODUCTION

The National Transmission Backbone Infrastructure (NBI) project aims at providing broadband services to government ministries, universities, schools, health centers, administrative headquarters and private sector entities in Uganda, and backhauling regional traffic from neighboring countries to the sea cable [7]. As discussed in [8], the NBI 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 [1] and [12] have highlighted a number of challenges facing the NBI project. The challenges include capacity and footprint limitations as well as high project cost and project management difficulties, as explained hereunder.

(i) ***Limited bandwidth due to the cable type installed***

The cable type installed in the NBI project is the G652 fiber-optic cable. This cable, according to research studies in [7], has some challenges that can compromise the performance of the cable. The challenges include Four Wavelength Mixing (FWM), high levels of chromatic dispersion, and a low dispersion distance. The G652 cable can only transmit 2.5Gbps, upgradable to 40Gbps using Wavelength Division Multiplexing (WDM). This is incomparable to the G655 which has an initial capacity of 40Gbps. Stakeholders believe, 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 set up five up-country centers allowing students to attend classes at the main campus through a video-link. The dispersion distance of the G652 is 70km, contrasted with that of the G655 cable which is over 210km. When using WDM, there is a tradeoff between dispersion distance and bandwidth of a fiber-optic cable. A G652 fiber-optic cable, for example, can have 2.5Gbps capacity with a dispersion distance of 1000 Km, 10Gbps capacity with a dispersion distance of 60 Km and 40Gbps capacity with 3 Km dispersion distance.

(ii) 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 that they can be distributed over a much wider area.

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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 International Telecommunications Union (ITU) are summarized in Table I, and the performance parameters are shown in Table II.

(iii) 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, [10] points out the fact that Karamoja and West Nile regions will not benefit from the NBI 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.

(iv) 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 timeously expanded.

TABLE I. OPTICAL CHARACTERISTICS OF G655 AND G652 [17]

Optical Characteristics	G655	G652
Attenuation at 1550nm (dB/km)	≤0.25	≤0.25
Dispersion (1530nm to 1625nm) (ps/nm/km)	1 – 14	14 – 23
Dispersion Slope (Ps/km/nm^2)	≤0.07	≤0.09
Effective Area (μm^2)	55	80
Mode Field Diameter (μm)	8.3- 9.7	10.1 –10.9
Channel Spacing (nm)	≤0.8	≤0.8

TABLE II. NETWORK PERFORMANCE PARAMETERS OF G652 AND G655 [17]

Network Parameters	G655	G652
No. 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

(v) Operation and maintenance of the infrastructure

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

(vi) Project cost

In addition to the aforementioned technical issues, experts as well as previous studies in [7] have raised concerns about the cost of deployment of the fiber-optic backbone. From Table III, it can be seen that Uganda is spending a lot more money than Rwanda, Afghanistan, Angola and Cameroon, to implement the NBI project [2], [7], [10], [13], [14].

(vii) The challenge of project management

In [7], 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.

TABLE III. NBI PROJECT COST FOR DIFFERENT COUNTRIES

Country	Cable length (km)	Cost (Million USD)
Uganda	2100	106
Rwanda	2300	38
Afghanistan	3200	64.5
Angola	8000	160
Cameroon	5600	163.3

Previous studies in [1] have modeled the national and international bandwidth requirements of the NBI project and demonstrated that there is a capacity gap between the installed and the desired bandwidth. Related studies in [7] have identified similar challenges and recommended a full technical audit of the NBI project. The question of operation and maintenance, especially the risk of fiber cuts, was also highlighted in [10]. The remedy proposed for fiber cuts was harmonization of excavation works. However, this remedy does not cater for cases of fiber cuts that occur by mistake. A fourth phase to lay fiber optic cable to areas left out in phase 1, 2 and 3, such as 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 paper revisits the traffic model in [1] 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 the Wavelength Division Multiplexing (WDM) technology. In addition, the paper proposes the commissioning of a Network Operation Center (NOC). Finally, the paper proposes the installation of WiMAX base stations as a last mile solution.

II. BACKGROUND

The Government of the Republic of Uganda, as part of the strategic programmes to achieve the MDGs, decided to set up a national transmission backbone infrastructure using fiber-optic cable. Fiber-optic cable was selected among several transmission media due to its advantages such as ability to support higher data rates, having error-free transmission over long distances, ease of handling, installing, and testing and long-term economic benefits [4], [11], [18]. 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 (NBI), as part of a project that was to be run by a Chinese company, Huawei Technologies [20].

A Task Team was consequently established by the Ministry of Information and Communication Technology (ICT), in order to: provide government with recommendations on the policy, legal and regulatory environment and the necessary changes thereto; to enable EGI and NBI; formulate national requirements and work with the contractor in fully defining and costing the initiatives; 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 e-government infrastructure would not be realized until the high level information systems become operational.

The contributions made by the Task Team included: contextualizing the project, that is to say, examining various key documents, including the Constitution; the Draft Vision 2035; the Poverty Eradication Action Plan (PEAP); The National ICT Policy; The Proposed New Telecommunications Sector Policy; the Proposed National Information Technology Authority-Uganda Bill; The Broadcasting Policy; and the Millennium Development Goals and related recommended strategies and demonstrating the need and justification for both EGI and NBI. 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, the time constraints could 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 National data transmission Backbone Infrastructure (NBI) and the E-Government Infrastructure (EGI). The NBI involves the establishment of a new stand alone network, independent of the existing infrastructure. The scope of the NBI encompasses laying 2,100 Kms of optic-fiber cables, together with the switching equipment and network infrastructure. The E-Government Infrastructure (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 [6].

The NDTBI and E-Government Project is a three phased project, estimated to cost US$127 Million [10]. The first phase, estimated at a cost of US$30 Million, involved the laying of 168 Kms 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 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 [10].The network architecture is shown in Figure 2.

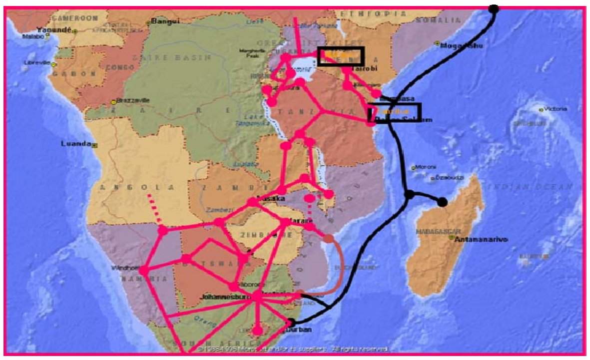

Figure 1. Backhaul links to EASSy Cable [6]

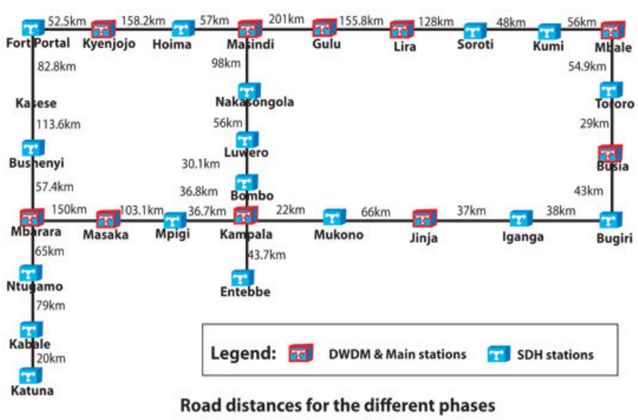

Figure 2. NBI architecture [1]

Phase 2 of the NBI component of the NDTBI project was scheduled to commence in the financial year 2008/09, and would involve laying of the 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 a Network Operations Centre (NOC) together with a modern Internet Exchange Point (IXP) [10].

Phase 3 involves the laying of the cable to connect the towns along Kampala, Mpigi, Masaka, Lyantonde and along 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 Centre 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 Centre 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 Statistics House [10].

III. ANALYSIS OF UGANDA'S BANDWIDTH REQUIREMENTS

In [1], Uganda's internet connectivity requirements are 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 NBI 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 to say the default contention ratio of 1:100 was used. Based on studies in [19], the bandwidth requirement per user for broadband services such as fast web browsing, video-conferencing, telemedicine and distance learning services was considered to be 256Kbps. This assumption differs from one made in [1] that the bandwidth required per connection would double annually, from 256Kbps in year 1, to 512Kbps in year 2, and so on.

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

National Bandwidth Requirement per annum	=Breq
National bandwidth usage per annum	=Buse
National Population	= P
Population per Institution	=pi
Total Population for all Institutions	=pt
Simultaneously Connected Users (%age)	=pu
Bandwidth requirement per User	=bu
Number of connections	=c

The bandwidth requirement and usage were computed using equations 1 and 2 respectively.

$$B_{req} = \frac{P * \left(\frac{p_t}{p_i}\right) * p_u * b_u}{10^3} \ldots\ldots\ldots\ldots\ldots (1)$$

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

In the model, the population growth rate of Uganda for the period 2005 to 2015, was taken to be 3.6% per annum, as indicated in [16], and the growth in Internet connectivity penetration taken to be 25.5% per annum [15]. 70% of the traffic was assumed to be originating from Kampala metropolitan area and 30% of the traffic assumed to be originating from areas outside Kampala. With the aforementioned assumptions and using equations 1 and 2, input data obtained from related studies [1] and [5] was extrapolated. The national bandwidth demand was modeled and the bandwidth usage as well as requirement 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 [1] 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.

The capacity of the fiber-optic cable network being laid in the NBI project is 2.5Gbps. When compared with the bandwidth usage and requirement of Figure 3 and Figure 4, it is evident that the NBI 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 like the G655 cable. The later option is very costly given the shortage of funds. The former option can be addressed using the alternatives explained in the next section.

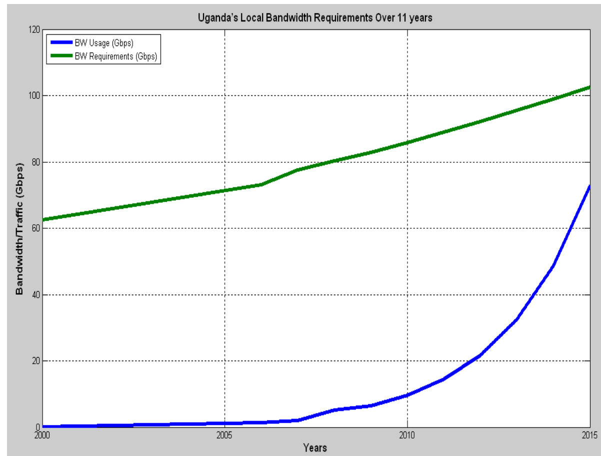

Figure 3. Uganda's National Bandwidth usage and requirement from 2000 to 2015

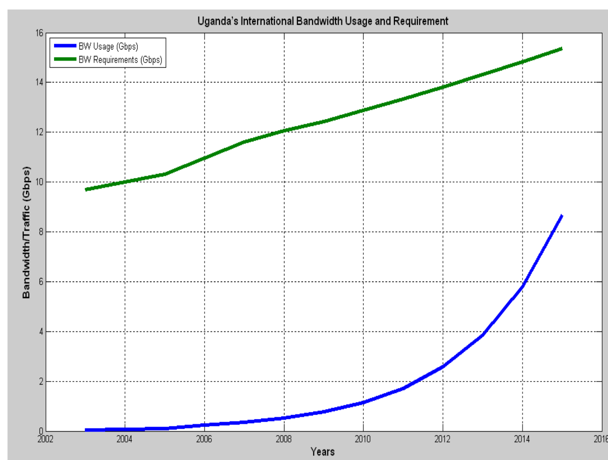

Figure 4. International bandwidth usage and requirement

IV. 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.

(i) Use of DWDM Repeaters after shorter distance.

This will increase capacity of the cable and fill the deficit identified in section 3. A G652 fiber-optic cable can have 2.5Gbps capacity when repeaters are placed after 1000Km, 10Gbps capacity when repeaters are placed after 60Km and 10Gbps capacity when repeaters are placed after every 3Km. We propose the use of repeaters after 3km in Kampala City, to increase the capacity of the cable from 2.5Gbps to 40Gbps. This follows the assumption that 70% of the traffic will be generated from Kampala and the rest will originate from areas outside Kampala. We also propose the use of repeaters after 60 Km in areas outside Kampala, to increase the capacity of the cable from 2.5Gbps to 10Gbps.

By 2015, the bandwidth requirement for the links serving the Kampala metropolitan area shall be 71.7Kbps and 30.7Kbps for links serving the rural towns, as shown in Figure 5. However, the current installed capacity is 2.5Gbps for links serving Kampala and the rural areas.

In Figure 5, we show that there is a deficit capacity requirement for all links. We therefore suggest the installation of 217 DWDM repeaters to enhance the capacity of the various links.

(ii) Installation of fiber cables over power lines

Studies in [18] 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. We therefore suggest the use of overhead or power line fiber-optic installation for phase 2 and 3 of the NBI 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 like MTN Uganda.

(iii) Leasing of bandwidth from private companies

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

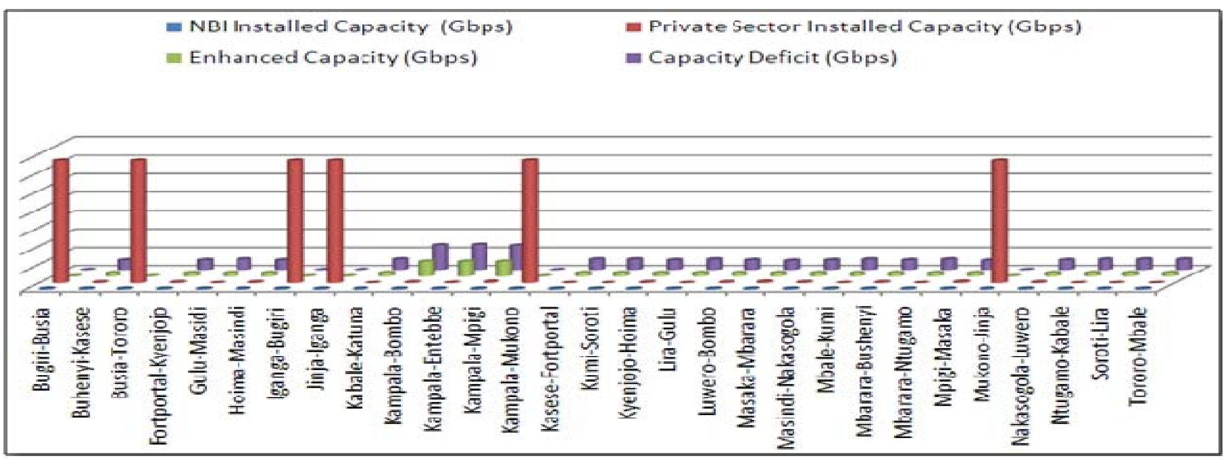

Figure 5. Installed, Enhanced and Deficit Capacity per NBI link (Gbps)

(iv) Implementing Redundancy

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

(v) Setting up a Network Operation Center

A Network Operation Center (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 will include configuration of capacity for different customers, repair and maintenance, as well as fault handling of occurrences of node faults and fiber cuts.

(vi) Extend the broadband coverage using WiMAX

Despite the fact that the NBI project is meant to benefit different institutions, the backbone is only connecting 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.

Figure 6. Rwanda's Network Operation Center (NOC) at Telecom House for Real-time Network Control & Monitoring [9]

Related studies in [1] and [9] have suggested the use of WiMAX as a broadband technology, to extend the footprint of the national backbone to remote areas which are not considered in the present design of the NBI network. WiMAX has been successfully used to provide access for hard to reach areas such as rural locations, places with 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 which involve all users and devices attaching directly to the wireless backbone and seamlessly integrating with networks inside buildings, police and fire vehicles.

V. CONCLUSION AND RECOMMENDATIONS

This paper investigated the technical challenges facing Uganda's National Backbone Infrastructure (NBI) 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 paper suggested ways of addressing the challenges of the NBI project using alternatives such as the use of Dense Wave Division Multiplexing (DWDM), leasing bandwidth from private companies, use of microwave links for redundancy, setting up a Network Operation Center (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 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 towards achieving the MDGs.

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APPENDIX 1: NBI PROJECT ACTIVITY

Figure 7. A team of engineers lay fiber optic cables