

Rural Connectivity Technologies Cost Analysis

F. Simba, L. Trojer, N.H. Mvungi, B.M. Mwinyiwiwa, E.M. Mjema

Abstract—Rural areas of Tanzania are still disadvantaged in terms of diffusion of IP-based services; this is due to lack of Information and Communication Technology (ICT) infrastructures, especially lack of connectivity. One of the limitations for connectivity problems in rural areas of Tanzania is the high cost to establish infrastructures for IP-based services [1-2]. However the cost of connectivity varies from one technology to the other and at the same time, the cost is also different from one operator (service provider) to another within the country. This paper presents development of software system to calculate cost of connectivity to rural areas of Tanzania. The system is developed to make an easy access of connectivity cost from different technologies and different operators. The development of the calculator follows the V-model software development lifecycle. The calculator is used to evaluate the economic viability of different technologies considered as being potential candidates to provide rural connectivity. In this paper, the evaluation is based on the techno-economic analysis approach.

Keywords—rural, connectivity, cost, V-model, techno-economic analysis.

I. INTRODUCTION

THE 23rd July, 2009 is a historic day to Tanzania; it is the day where Tanzania was connected to the rest of the world through a submarine optic fibers cable, the SEACOM, which is envisioned to lower cost of connectivity[3]. SEACOM, a privately funded venture, owns and operates a submarine fibre-optic cable that will connect communication carriers in South and East Africa through the wholesale of international capacity to global networks via India and Europe [4]. Observation from IT experts in the country suggests that: unless there is a connection within the country that joins end user to the SEACOM fiber cable – the cost of connectivity will remain high to the end user and capacity of the fiber cable will be under-utilized [5]. However, efforts are underway to implement the national fiber optic backbone with coverage of up to district level [6]. Despite this initiative, some rural areas are remotely located to the extent that their total coverage will take sometimes.

On the other hand, Tanzania is also equipped with eleven (11) telecenters, aimed to provide ICT related services to rural areas; one of them is Sengerema telecentre. In Oct, 2008, the Tanzania Telecentre Network (TTN) in collaboration with

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IICD set up a pilot wireless mesh network. The goal of the mesh network is to make internet available and affordable to large numbers of people who live in the rural areas around the telecentre [7]. The wireless mesh network launched in Sengerema, connected ten (10) local organisations to the internet through the Sengerema Telecentre. The mesh network is built by connecting one node installed with omni-directional antennas to the nearby nodes that are installed with directional antennas. The mesh network can provide coverage of less than 3km [8]. Even with the fiber optic and mesh networks initiatives, some rural and remote areas can still be unconnected; hence some other connectivity options are required to accommodate the remote areas to the existing internet connectivity initiatives. Therefore aim of this paper is to analyses cost of establishing connectivity within the country, especially in the rural areas that are mostly disadvantaged in terms of ICT infrastructures. The rest of this paper is organized as follows: section II present connectivity cost calculator development based on V-model approach. Section III is on Techno-economic analysis for different technologies with the potential to provide rural connectivity. Results discussion are in section IV and section V conclude the paper.

II. CONNECTIVITY COST CALCULATOR DEVELOPMENT: V-MODEL APPROACH

The V-model is an internationally recognized development standard for IT systems which uniformly and bindingly lays down Procedures, Methods and Tools [9]. The V-model is a structure imposed on the development of a software products (software life cycle) which can be presumed to be the extension of the waterfall model shown in figure 1.

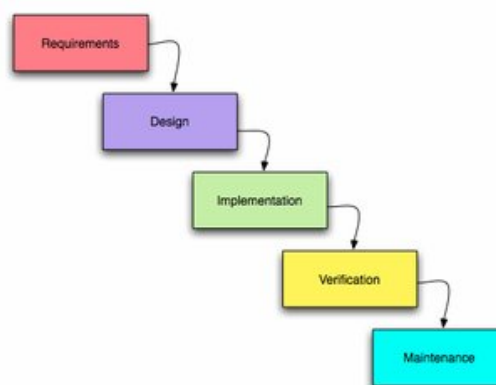


Fig. 1 Waterfall Model Software Lifecycle

With this model, the process steps are bent upwards after the coding phase, to form the typical V shape instead of moving down in a linear way. The V-Model demonstrates the relationships between each phase of the development life cycle and its associated phase of testing. The V-model deploys a well-structured method in which each phase can be implemented by the detailed documentation of the previous phase. Testing activities, like test designing, start at the beginning of the project well before coding and therefore saves a huge amount of the project time [10].

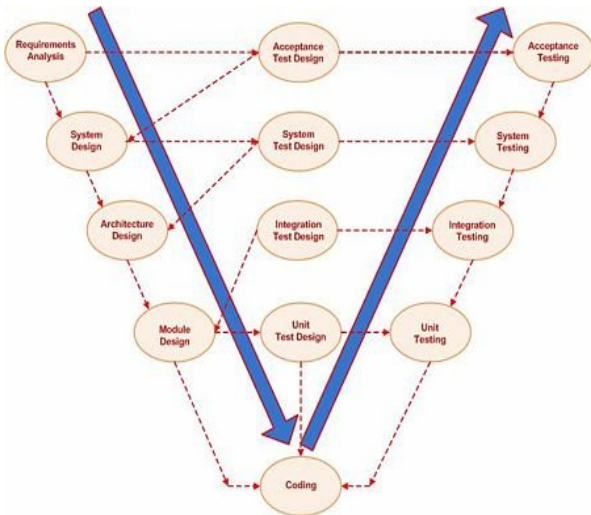


Fig. 2 V-Model Software Development Process (Software life cycle)

I. System Design and Development

System design and development steps were done by following the v-model framework. In the requirements analysis phase, the requirements of the connectivity cost calculator system were collected by analyzing the needs of the users. Users of this system are the schools management, government or donor projects who want to know cost of establishing connectivity to a particular school. Data for requirement analysis were collected through oral interviews where results show that users are interested to know which technologies are available, what are their associated costs, who can provide it (operator/service provider)?. The user requirement document was specified that explains the functional requirements and non-functional requirement of the system. The user requirement document from the requirement analysis serves as a guideline to design the system organization (system blueprint) which shows what will be the sample windows (interfaces). Entity diagram and data dictionary were prepared in this phase, they specifies relationship between entities and data structures in the system. Thereafter a testing strategy was established that specifies in which steps testing will be performed during the system development. The system was designed in modules; these are small units each of them accomplishes a particular task and a collection of all the modules makes up the whole system. The system was also developed in modular phases where pieces of the systems were developed separately and thereafter they were integrated to

form a complete system. Each module was tested separately to make sure that it performs as it was planned to do. Testing was also conducted after each module's integration, and finally the whole system was tested.

II. The Implemented System Screenshots

Figure 3 shows the system home page (interface). Users are required to register in order to access the calculator. Once registered then they will be only required to login prior to access the calculator.

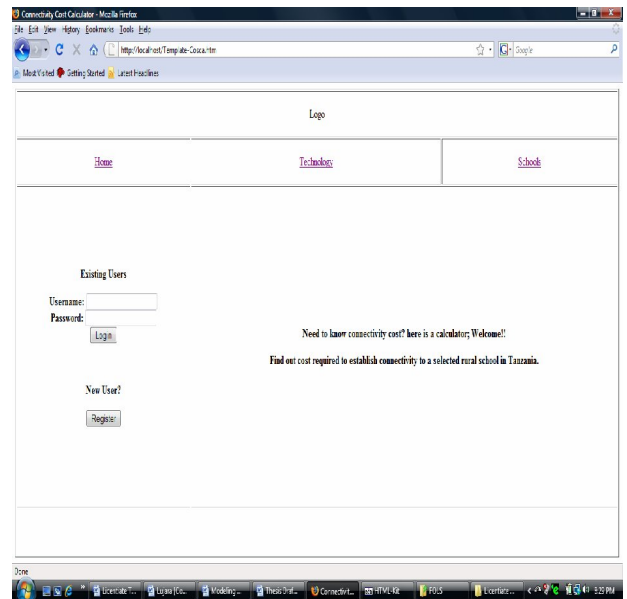


Fig. 3 Connectivity Cost Calculator Homepage

The calculator provides two services; cost calculation or cost comparison as shown in figure 4. The cost calculation enables one to determine a cost of establishing connectivity to a particular school from one type of technology and operator. The cost comparison service determines the difference in cost between two selected technologies that are capable to provide connectivity to a selected school.

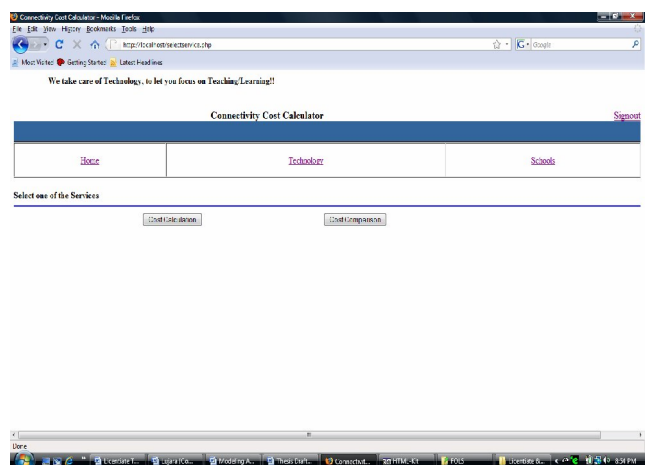


Fig. 4 Services provided by the cost calculator (cost calculation or comparison)

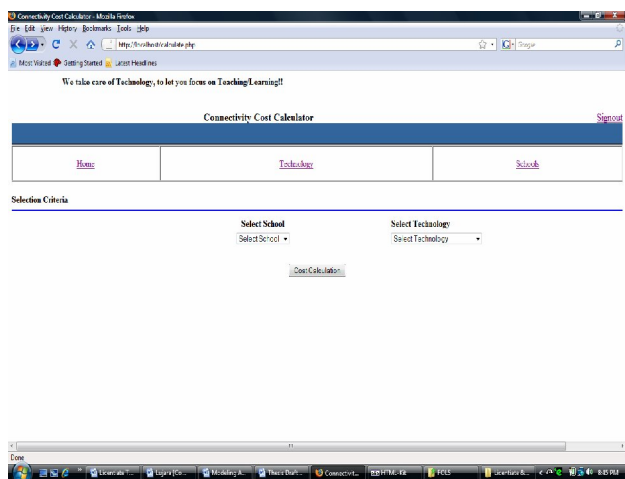


Fig. 5 School and Technology Selection

For cost calculation, a user has to select name of the school he/she wishes to know/calculate its cost for connectivity establishment. Once a school is selected, the combo box to select technology will be enabled and it will contain only technologies that are capable to reach the selected school, refer to figure 5. Technologies that are available in the country but due to technical reasons (e.g network coverage) cannot be used to connect the selected school will not be displayed in the “Select Technology combo box”. Thereafter, size of the network to be connected is specified. Installation cost and monthly charges that are different from one operator to another will be automatically filled in their respective fields according to the selected technology.

The developed connectivity cost calculator is one step away to complete the v-model software lifecycle i.e it is not yet done with the user acceptance testing. However, the calculator serves as a tool to make easy access to the cost of connectivity. With the calculator it is possible to know which technologies are available for network connectivity to your place (schools in this case). The calculator will provide a connectivity cost as well as cost comparisons to the available technologies. The system is aimed for schools management, government and/or donors who wish to know cost of establishing connectivity to a particular schools/area in the country. In addition to the cost calculation and cost comparison; it is worth to know the economic viability of different technologies that have potential for rural connectivity.

III. TECHNO-ECONOMIC ANALYSIS

One of the challenges that hinder diffusion of IP-based services in rural areas of Tanzania is the lack or limited ICT infrastructures. The situation is spearheaded by the high cost of establishing the ICT infrastructures especially to the rural areas [1]. However by January, 2009, Tanzania had twelve (12) registered and licensed operators [11] with different options (different technologies) to provide ICT network facilities and services in the country. Most of the available operators have network coverage in the cities; their business

models are unfavorable to the rural areas due to high deployment and maintenance cost. This section aims to identify a suitable technology for rural connectivity; the selection of the best technology is usually based on a technical consideration as well as on the financial investment and operational costs of the network. To obtain the above values, an economic evaluation is required (techno-economic analysis). Two measures are usually assessed when performing a financial evaluation of a network [12]: the CAPEX (capital expenditure) and the OPEX (operational expenditure). Authors in [12] [13] define the following economic terms as follows: CAPEX as an initial, one-time investment, for example the price of the equipment, the software and the installation costs. OPEX represent the recurring cost expended by the service provider. This may include maintenance of the network connections, monitoring of the system, the system support and the cost of the transmission media.

The intended network development is towards lower CAPEX and OPEX architectures with converged (data, voice and video) services. Therefore, a financial assessment of the overall technology deployment is done based on techno-economic evaluation measures such as Net Present Value (NPV) and Internal Rate of Return (IRR). Later, the NPV and the IRR are used as indicators, first to evaluate the technology, and then to choose the most appropriate technology. NPV is the future stream of benefits and costs converted into equivalent values today. This is done by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted costs from the sum total of discounted benefits. NPV is an indicator of how much value an investment or project adds to the firm. Table 1 explains what does the calculated value of NPV means:

TABLE 1
 MEANING OF NPV VALUES [14]

If...	It means...	Then...
NPV > 0	the investment would add value to the firm	the project may be accepted
NPV < 0	the investment would subtract value from the firm	the project should be rejected
NPV = 0	the investment would neither gain nor lose value for the firm	Be indifferent in the decision whether to accept or reject the project. This project adds no monetary value. Decision should be based on other criteria, e.g. strategic positioning or other factors not explicitly included in the calculation.

For a given fixed time T , the IRR represents the value of the rate r such that $NPV(T) = 0$. In other words, over time T , IRR represents the rate of return on the initial investment. *Time to break-even* is another economic term that represents the smallest time t by which the service provider is able to regain the entire investment. In other words, this is the minimum value of t such that $NPV(t) > 0$. A technology with a lower Time to break-even is preferable over another technology with a larger Time to break-even. In this paper, cost of different connectivity technologies to the rural areas are evaluated and compared based on the techno-economic analysis.

A. CAPEX and OPEX Calculations for Connectivity Technologies to Rural Tanzania

In planning a network, costs are important aspects to consider. The importance increases, especially when planning for rural and low income customers. Network/connectivity costs can be identified by using cost models; cost models are usually used to calculate the cost of providing a given service to a particular customer in a specified location [15]. The approach taken in this paper is based on analytical modeling of network costs that involves CAPEX and OPEX calculations. The CAPEX and OPEX values give a picture of an economic standpoint of different technologies. The CAPEX comprises of network equipments costs and installation costs while the OPEX is made up of monthly charges (recurrent costs). The CAPEX are technology dependent while OPEX depends on both technology and the required capacity (bandwidth). Equipment cost is a summation of equipments at end user premises and equipments at the service provider's side. Therefore, connectivity costs for a particular client (school) can be calculated by using the following general formula:

$$C = (\text{CAPEX}) + (\text{OPEX}) \quad (1)$$

In this case all costs are calculated for a 5-year time span. This period is chosen due to the consideration that; after 5 years a network might need an upgrade, hence an additional CAPEX or after 5-years a new technology may emerge. The selected technologies for cost analysis are the wireless family that exists in the country: Cellular, VSAT, Wireless Local loop (WLL) and WiFi-based outdoor Long Distance (WiLD). The WiLD is used for cluster connectivity where a group of customers connect to a single centre to access a shared resource (a cost sharing model).

1) Cellular Network Technology

There are two options noted from the tariff tables of the mobile (cellular) network operators; buying in terms of bundles with a monthly subscription fees and another alternative is a "pay as you use" option. A suitable approach to organization like a school is buying in bundles with monthly subscription; it is possible to manage usage of the amount of capacity available (bundle). It is also changed relatively cheap compared to the other alternative (pay as you use). Now, considering an ideal school with 20, if each computer will be used to download at most 100 MB in a month, and then

assume that a school is subscribed in Vodacom MyGig Two. Cost of connectivity can be calculated as follows:

Equipment required: 3G HSDPA USB Modem (E220), it is a preferable hardware for laptops and computers without a PC-card slot. The USB Modem works with Vodacom's 3G HSDPA network where available and slips seamlessly into Vodacom's upgraded GPRS network.

Its current price is Tsh 345,000 (inclusive taxes).

Equipment cost = $20 \times 345,000 = \text{Tshs } 6,900,000$

Installation cost = 0

Recurrent fee (monthly Subscription) = 163,840

Total cost per month Tshs $(6,900,000 + 163,840)$

= Tshs 7,063,840

Total cost in 5 years = Tshs $(6,900,000 + 163,840 \times 60)$

= Tshs 16,730,400

= US\$ 16,731

2) Satellite (VSAT) Technology

Using data collected from Infrastructure survey in Africa-online (T) Ltd, an Internet Service Provider (ISP), here is the cost information for VSAT connectivity with 512/128 Kbps downlink/uplink speed.

Equipment cost = Antenna + Modem = US\$ 4,500

Installation cost = US\$ 1,500

Recurrent fee (monthly Subscription) = US\$ 1,500

Total cost per month = US\$ $(1,500 + 1,500 + 4,500) = \text{US\$ } 7,500$

Total cost in 5 years = US\$ $(1,500 + 4,500 + 1,500 \times 60) = \text{US\$ } 96,000$

3) Wireless Local Loop (WLL)

Using data collected from Infrastructure survey in TTCL (T) Ltd, here is the cost information for Wireless Local Loop (WLL) connectivity. The service is available in four regions; Arusha, Mara, Morogoro and Tanga.

Equipment cost = Wireless access point (radio) = US\$ 800

Installation cost = US\$ 100

Recurrent fee (monthly Subscription) = US\$ 400

Total cost per month = US\$ $(800 + 100 + 400) = \text{US\$ } 1300$

Total cost in 5 years = US\$ $(800 + 100 + 400 \times 60) = \text{US\$ } 24,900$

4) Wifi-based Long Distance Links (WiLD) for Clusters

Consider n number of schools connected in a cluster as shown in figure 1. WiLD links are used to form cluster connectivity between schools and a cluster centre. Resources shared are stored at the cluster centre and update of the shared resources is done by using cellular infrastructures.

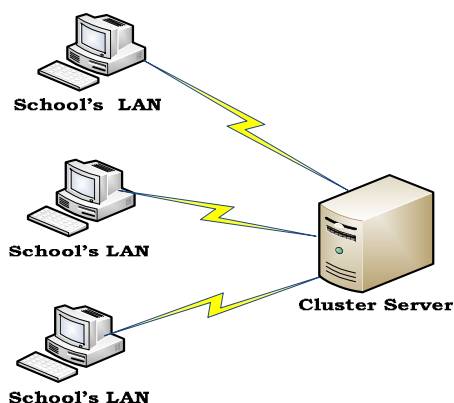


Fig. 1 WiLD links for cluster connectivity

TABLE II
 EQUIPMENTS AT THE CLUSTER CENTRE

S/N	Equipment	Tech Specs	Amount	Cost(US\$)
1	Sector Antenna	15dBi 180 ⁰	1	230
2	Wifi Radio (AP)	D-Link DWL-2100AP	1	99
4	USB modem for GPRS	USB modem (E220)	1	345
	Tower		1	5000
Subtotal A			5	5674

TABLE III
 EQUIPMENTS AT SCHOOLS SIDE

S/N	Equipment	Tech Specs	Amount	Cost (US\$)
1	Directional Antenna	19dBi 8 ⁰	1	200
2	Wifi Radio (AP)	D-Link DWL-2100A P	1	99
4	Tower		1	5000
Subtotal B			3	5299

Authors in [16] reported costs of towers as shown in table 4. However at height of 10 to 15 meters, they used a mast consisting of a water-pipe instead of towers to minimize costs. Assuming a worst case scenario where schools cluster uses 45 meters high towers in each site, assumption is made to calculate maximum cost of cluster connectivity, since overall cost is dominated by tower costs. However a cost-conscious

option could be using 10m or 15m masts on top of tall school buildings. Assume 5 schools are connected in this cluster.

TABLE VI
 COSTS OF TOWERS AS REPORTED BY RAMAN AND CHEBROLU (2007) [16]

Tower/mast height (m)	10	15	21	24	27	30	45
Cost (\$)	100.00	150.00	800.00	950.00	1100.00	1850.00	5000.00

The DWL-2100AP features WDS (Wireless Distribution System) that can be configured to perform in any one of four modes: a Wireless Access Point, a Point-to-Point (PtP) bridge with another DWL-2100AP, a Point-to-Multipoint (PtMP) bridge, a Repeater for range extension, or as a Wireless Client. The DWL-2100AP is also fully compatible with the IEEE 802.11b and 802.11g standards. Cost of connectivity to a single school connected in a cluster can be calculated as follows:

Equipment cost = ((Subtotal A)/n + Subtotal B); where n = number of connected schools

$$= (5674/5) + 5299$$

$$= 6433.8$$

Installation Cost = InstA/n + InstlB (assume installation cost of US\$ 100 as that of WLL)

$$= 100/5 + 100$$

$$= 120$$

Recurrent cost = Rec/n = 0 (no monthly charges; the network is installed for local traffic)

Cost per school per month = [((Subtotal A)/n + Subtotal B) + (InstA/n + InstlB) + Rec/n]

$$= (6433.8 + 120 + 0)$$

$$= 6553.8$$

Cost in 5 years = [((Subtotal A)/n + Subtotal B) + (InstA/n + InstlB) + (Rec x 60)/n] = 6553.8

IV. RESULTS DISCUSSION

Figure 3 represent only initial investment cost; CAPEX, with its associated components (installation and equipment costs) form different technologies per school. Three technologies, namely; cellular, VSAT and WiLD are noted to have high initial costs. Equipments costs required to set up the network dominate the overall initial investment cost.

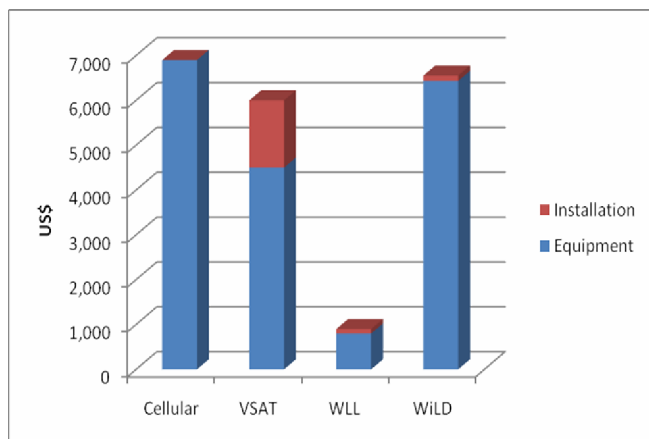


Fig. 3 Comparison of initial investment cost (CAPEX)

Figure 4 represent financial investment of establishing connectivity to rural areas in Tanzania with different technology options.

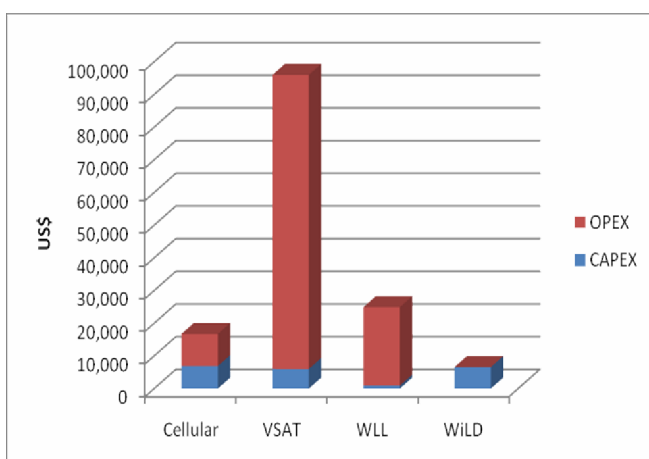


Fig. 4 Economic costs (CAPEX + OPEX) comparison per school after five (5) years by different technologies.

Results reveal that; WiLD connectivity followed by cellular technologies emerges to be cheaper options after five (5) years of implementation. Cost in each coming year after initial implementation is dominated by recurrent cost. Cellular infrastructure is further backed up by its ease of implementation (deployment) and direct access to the internet. However it is challenged by unreliable speed and narrow data capacity (bandwidth). For example, Vodacom offers best effort speeds to the internet of up to 32kbps. Data transfer speeds are not guaranteed and depends on network availability and utilization [17]. WLL has lowest initial investments but its coverage spans only four regions in the country. Going for this option (WLL) means new investments is required to implement the supporting backbone, which might be expensive both in initial costs (CAPEX) and time. Another disadvantage of WLL is the high recurrent cost which means after five years, its overall cost is higher than cellular and WiLD infrastructures that had higher initial costs compared to WLL. The VSAT option is unattractive (expensive) both in initial cost and costs after five (5) years. WiLD (cluster) connectivity is

encouraging despite of its high initial cost; in subsequent years, the cost will remain constant until when network upgrade or repair is required. Despite its low cost, it doesn't have access to the rest of the world (internet); these are local clouds where schools are sharing only local contents.

V. CONCLUSION

In this paper, connectivity establishment to rural secondary schools is considered as an initiative by an individual school, a government initiative or a donor project. So it is not a business or for-profit project where one could expect revenue out of it. Therefore it was not possible to calculate NPV or IRR for these deployments taking into consideration that NPV and IRR involve revenue part of the investment. However from the CAPEX and OPEX calculation; which is a part of techno-economic analysis, it was possible to get an insight on the required financial investments to establish connectivity from different technologies. Furthermore, the financial investment comparisons, displayed a cheap connectivity option for the five years life span; the WiLD. Due to its costs attractiveness, this paper recommend WiLD technology option for rural connectivity that are isolated (i. e there is no any connectivity coverage nearby). However, the WiLD architecture can be upgraded to access the internet by connecting the cluster center to the internet. Thereafter, the internet access at the cluster centre can be shared by the rest of the schools connected to the cluster and so is the cost of internet access. It is envisioned that this approach will further bring down cost of connectivity to individual schools.

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REFERENCES

- [1] Sedoyeka, E. Hunaiti, Z. Al Nabhan, M. Balachandran, W. (2008). WiMAX Mesh networks for underserved areas. In Proceedings of the 2008 IEEE/ACS International Conference on Computer Systems and Applications - Vol 00. Pp 1070-1075. ISBN: 978-1-4244-1967-8. IEEE Computer Society Washington, DC, USA.
- [2] Simba, F., Mjema, E.C., Mvungi, N.H., Lena, T., Mwinyiwiwa, B.M.M., (2009). Strategies for Connectivity Configuration to Access e-Learning Resources: Case of Rural Secondary School in Tanzania. In Proceedings of World Academy of Science and Technology. ISSN 2070-3742. Vol. 54. Pp 889 – 894. Paris, France.
- [3] The Guardian. (2009). The Tanzania local news paper accesses online via the ippmedia <http://www.ippmedia.com/frontend/index.php?l=5095> Accessed on 23rd July, 2009.
- [4] SEACOM (2009). Seacom Goes Live in East Africa <http://www.seacom.mu/intro.html> accessed on 23rd July, 2009
- [5] eThinkTanktz, (2009). Seacom has arrived..... <http://groups.yahoo.com/group/eThinkTankTz/> . Accessed on 27th July, 2009
- [6] MST Minister's Speech, (2009). http://www.mst.go.tz/index.php?option=com_content&view=article&id=64&Itemid=94 accessed on 23rd July, 2009.

- [7] Lenoir, M. (2008). Building a Wireless Mesh Network in Sengerema, Tanzania
<http://www.iicd.org/IICDCorporateBlog/categories/articles/launch-of-wireless-internet-in-sengerema-tanzania/>
- [8] TTN Report (2008). A TTN workshop: The Sengerema Wireless Shared Community Network
October 19-24 2008.
<http://www.swopnet.or.tz/docs/sengeremawirelessshared.pdf> accessed on 28th July, 2009.
- [9] Geocities, (2009).
<http://www.geocities.com/rmtiwari/main.html?http://www.geocities.com/rmtiwari/Resources/Management/SoftwareDevelopmentLifecycle/V-Model.html> accessed on 22th july, 2009.
- [10] free encyclopedia, (2009). [http://en.wikipedia.org/wiki/V-Model_\(software_development\)](http://en.wikipedia.org/wiki/V-Model_(software_development)) accessed on 20th July, 2009.
- [11] TCRA, (2009). List of licensed Service Providers in Tanzania.
http://www.tcra.go.tz/licensing/CLFlicensed_operators.php accessed on 19th July, 2009.
- [12] Jerman-Blažič, B (2007). Techno-economic analysis and empirical study of network broadband investment: The case of backbone upgrading. Journal of Information Systems Frontiers. Volume 10, Number 1. Pp 103-110. ISSN 1387-3326 (Print) 1572-9419 (Online). Springer Netherlands.
- [13] Mishra, S. M., Hwang, J., Filippini, D., Moazzami, T. D, R. and Subramanian, L. (2005). UCB Technical Report UCB/CSD-05-1411: Economic Analysis of Networking Technologies for Rural Developing Regions.
- [14] Wikipedia, (2009) http://en.wikipedia.org/wiki/Net_present_value accessed on 28th July, 2009.
- [15] Cadman, R; Dineen, C; Twomey, P. 2006. Trends in Economics and Finance. Volume II: Use of Economic Modeling in Telecommunications. ITU Report.
- [16] Raman, B and Chebrolu, K. (2007) "Design and Evaluation of a new MAC Protocol for LongDistance 802.11 Mesh Networks". In *ACM MOBICOM*.
- [17] Vodacom Internet Bomba, (2009).
<http://www.vodacom.co.tz/docs/docredir.asp?docid=3569> accessed on 23rd July, 2009.