GEOSPATIAL MAPPING OF FIBRE OPTIC DISTRIBUTION NETWORK IN CENTRE FOR RELIGIOUS EDUCATION AND SOCIAL SERVICES, DAR ES SALAAM TANZANIA

BY

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ABSTRACT

Several private and government institutions, schools, enterprises, universities and companies, having realized the importance of Fibre optics deployment are focused on adopting the technology to increase bandwidth for high-speed internet connection. Unreliable internet connection in The Centre for Religious Education and Social Services of the Archdiocese of Dar es Salaam, Tanzania has been a major issue affecting the efficient delivery of the Institution's activities for several years. This study used geospatial tools to analyze the existing distribution of internet connection within the Centre and proposed suitable routes for Fibre Optic Network distribution in order to enhance internet connection coverage. The objectives included: examining the existing internet connection devices; mapping the internet connection coverage area of the existing UTP technology; and propose suitable routes for fibre optic distribution to enhance the total coverage of the study area. The method included planning the Fibre optic network using specialized remote sensing and GIS systems to prepare the required geospatial data of the study area. The established application performed all required pre-processing of the geographic data to prepare the essential information for mapping the Fibre Optic distribution and the proper route for Fibre optic cables, in the coverage area. The results revealed the complete coverage of the proposed Fibre optic deployments in the study area and recommended the immediate execution of strategies to implement the proposed project in order to improve internet connection in the Centre.

Keywords: Fibre Optic Technology, Geographic Information System, Internet Connection, Remote Sensing, Unshielded Twisted Pair

INTRODUCTION

Unreliable internet performance is a significant challenge in Tanzania, impacting the efficient delivery of services in institutions like The Centre for Religious Education and Social Services of the Archdiocese of Dar es Salaam. The institution has been striving to have reliable internet connection infrastructure, but the Unshielded Twisted Pair (UTP) Cable Technology backbone is no longer able to provide reliable internet connection due to the expansion of activities such as teaching, research, and conferences. It is a crucial necessity for society, education, and all kinds of economic development to have reliable and efficient internet connectivity.

As demand for better connectivity has arisen, it has become highly desirable to upgrade with Fiber optic technology; however, the approach faces many complications in planning a new network due to the varied terrain and infrastructure characteristics of the locality. It must rely on a knowledgeable, geospatially-directed approach to optimize the construction of a Fiber optic network that can guarantee equitable access for all users in the area.

Unshielded Twisted Pair cables (Figure 1.1) are susceptible to Radio frequency Interference (RFI) and Electromagnetic interference (EMI), and more prone to electronic noise interference than other forms of cable (Ronnie, 2020). Additionally, the distance between signal boosts is shorter with UTP cables than Fibre optic cables, making it less able to carry signals for long-distance networking (Pigg, 2004).

The internet is a large computer network linking millions of smaller computers at numerous sites in various countries belonging to thousands of businesses, governments, research, educational, and other organizations (Emeka & Nyeche, 2016). Fast internet access is widely considered a productivity-enhancing factor, but there are little rigorous research quantifying benefits to individual firms from upgraded internet connectivity (Yebowaah, 2018).

Unshielded Twisted Pair is the copper media, inherited from telephony, being used for increasingly higher data rates and is becoming the de facto standard for horizontal wiring (Thakur, 2021). Shielded Twisted Pair (Figure 1.2) is heavier and more difficult to manufacture but can greatly improve signal rate in a given transmission scheme.

According to Dinc et al. (2021), coaxial cables carry signals of higher frequency ranges than twisted pair cables, with a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath (Figure 1.3). The outer conductor is protected by a plastic cover and serves as a shield against noise and as the second conductor (Maisammaguda, 2019).

Optical fibre carries information at frequencies in the visible light spectrum and beyond (Maisammaguda, 2019). The typical optical fibre consists of a narrow strand of glass called the core and a concentric layer of glass called cladding (Figure 1.4). A fibre-optic cable is made of glass or plastic and transmits signals in the form of light. Fibre optics technology has been in existence for over 40 years, and it is the most advanced and modern mode of data communication. It allows communication signals to be transmitted from one location to another in the form of light guided through thin fibre of glass or plastic (Fibre Optics Association, 2014) (Figure 1.5). This technology has theoretically unlimited bandwidth, making it more secure than other data transmission systems like satellites (Biswas, 2017).

Fibre Optic Network is an element of the network infrastructure that provides high-speed and high-capacity connections among networks (Thakur, 2021). It is more secure than other data transmission systems, immune to interference and crosstalk, and has a potentially limitless capability (Ramaswami & Sivarajan, 2002.). First-generation optical networks used Fibre optic as a replacement for copper cable to get higher capacities and lower bit error rates.

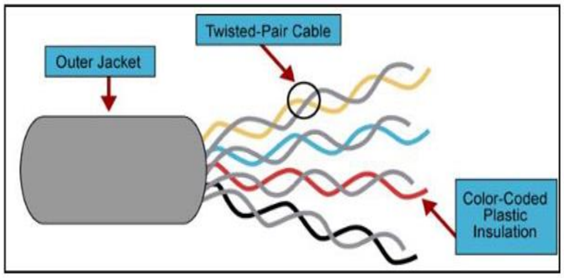

Figure 1.1: Parts of Unshielded twisted pair (Sheldon, 2013)

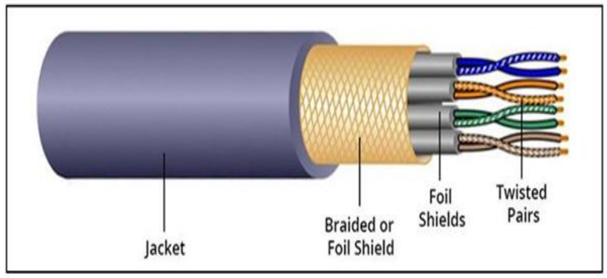

Figure 1.2: Parts of Shielded twisted pair (Sheldon, 2013)

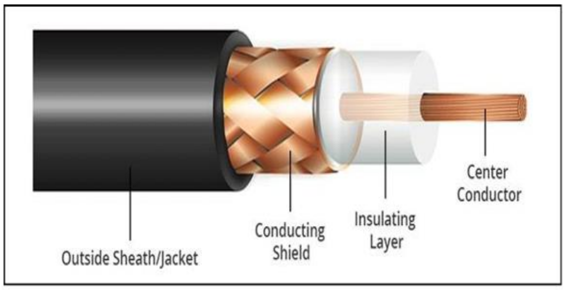

Figure 1.3: Parts of Coaxial Cable (Sheldon, 2013)

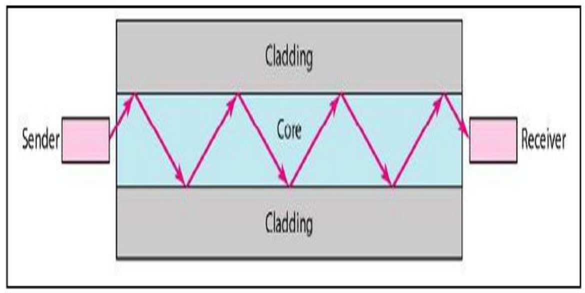

Figure 1.4: Propagation of signals through the core of Fibre optic cable (Maisammaguda, 2019)

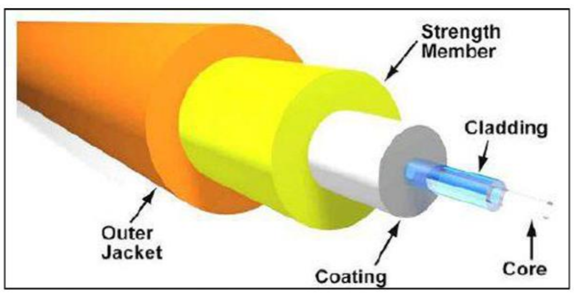

Figure 1.5: Parts of Fibre optic cable (Maisammaguda, 2019)

Subramani and Kumar (2012) opined that Fibre optic technology offers many additional benefits in terms of cost and performance over any other communications network technology. It can carry ten times more data than UTP copper cable and is more secure, reliable, and durable than copper cables (Kowero, 2012). They are also resistant to Electrical Noise, Interference, and Voltage surges. In addition, Fibre cables are designed to last 30-50 years (Anderson, 2019).

Geographic Information Systems (GIS) is a crucial tool for collecting, managing, and presenting spatially referenced data to suit user demands (Longley et al., 2005). It has been developed across various disciplines, including geography, cartography, photogrammetry, remote sensing, surveying, geodesy, civil engineering, statistics, computer science, operations research, artificial intelligence, demography, and more (Tang, 2005). GIS can transform any piece of data into useful information, providing a database and images of the area of study. It also allows for better statistical analysis, enabling intelligent decisions (National Geo, 2017).

In the telecommunications industry, GIS functions as a network inventory, providing reports on the management of the fibre-optic cable network. It offers advantages such as reduced manual tracing of cables on site by field engineers, improved data handling, spatial analysis and automation capabilities that increase the speed and accuracy of network design processes. Rule-based features in GIS can help network designers produce better products optimized for cost, shortest routing distances, or other user-defined metrics.

The deployment of a fibre optics network requires good planning and pre-knowledge about the study area infrastructure. GIS environments can be used to examine and prepare required data quickly and accurately, saving time and money. Google Earth can be used for visualizing network plans, supporting network planning by reducing the need for physical site visits for inspection and verification (Pedersen et al., 2010). Design calculations are based on real geographic data and infrastructural information of the targeted area (Omogunloye et al., 2013).

In this research, GIS data analysis was implemented to plan the suitable route for fibre optic distribution. The study include: examining the existing internet connection devices in the Center for Religious Education and Social Services Dar es Salaam; mapping the internet connection coverage area of the existing UTP technology; and proposing suitable routes for fibre optic distribution to enhance the total coverage and ensure reliable internet connection in the study area.

THE STUDY AREA

The study area is the Centre for Religious Education and Social Services of the Archdiocese of Dar es Salaam which is located in Ilala Municipal, Tanzania within Latitudes 6° 49' 15" - 6° 49' 45" South and Longitudes 39° 15' 15" - 39° 15' 45" East (Fig. 2.1). It is bordered on the East by Kigogo Highway Road and Regional commissioner headquarters; the South by Uhuru Street. The total area covered by the institution is 1.61 Kilometers and is estimated to have more than 150 workers in its employ (Msimbazi Centre, 2019).

The major objective of the Centre is to eradicate poverty through the provision of education by conducting educational activities to adults, supplemented with facilities for sleeping, catering, bookshops etc. Activities were later extended to include home craft school and the use of halls for seminars, conferences, workshops, and other activities, which involve large gatherings.

The Institution can be categorized into two parts which include Msimbazi Centre and Msimbazi Mission. There are 10 departments within the Msimbazi Centre namely: Administration, Finance and Bar, Men’s Hostel, Women’s Hostel, Bookshop, Home craft School, Adult Education, Canteen, Workshop, Garage. The Institution can be categorized into two parts which include Msimbazi Centre and Msimbazi Mission. There are 10 departments within the Msimbazi Centre namely: Administration, Finance and Bar, Men’s Hostel, Women’s Hostel, Bookshop, Home craft School, Adult Education, Canteen, Workshop, Garage. The area within Msimbazi Mission has College(s), St. Augustine University, Residential area, Hospital and Schools.

Figure 2.1: Map of the Study Area (Google Earth Pro, 2024)

Internet connectivity in the Study Area

The Unshielded Twisted Pair CAT 5e and CAT 6 technology has been used as a backbone for connecting the internet network at the Centre for Religious Education and Social Services of the

Archdiocese of Dar es Salaam. Unshielded Twisted Pair is a very flexible, low-cost transmission media which is appropriate for data communication.

According to Ronnie (2020), UTP cable technology has many disadvantages compared to Fibre optic cable technology deployment. Unshielded Twisted Pair cables are highly affected by disturbances particularly Radio Frequency and Electromagnetic Interferences, leading to increased exposure to electronic noise relative to other cable types. In addition, the distance between signal boosts is shorter with UTP cable compared to Fibre Optic Cables, making it less able to carry signals to for long-distance networking.

Various models have been used to combat the issue of Unreliable internet connection including; devices upgrade; changing from UTP cable CAT 5 to CAT 6 technology; migration from one Internet Service Provider to a better alternative and ensuring regular maintenance checks. During this period, provision of internet devices like Router which is a powerful networking device for boosting signal and increasing the performance of internet were changed from one vendor to another for the purpose of increasing the performance of internet connection. The new vendor was mandated to change the current point to point access point devices for wireless signals communication to enhanced signal transmission.

Contract with Internet service provider like Net Solution Limited was terminated and another company, the Tanzania Telecommunication Company was given the task to deploy the internet connection in the Institution. Buildings with old UTP connection were also upgraded from UTP CAT 5e technology to UTP CAT 6 technology. Due to the internet downtime, regular maintenance was performed on the existing internet connection (Msimbazi Centre, 2019).

MATERIALS AND METHODS

The study carried out in 2024, adopted a systematic approach for mapping the Fibre optic network infrastructure (Msangawale et al., 2011). Remote Sensing and GIS data was collected for developing fibre optic network for easy deployment process. The method established different steps involved in proposing the Fibre optic network starting from using specialized remote sensing and GIS software to prepare the required geospatial data of the study area. The established application performed all required pre-processing of the geographic data for mapping the proposed Fibre optic distribution and designating the proper route of Fibre optic backbone and drop cables in the study area. The workflow diagram is given in (Figure 3.1).

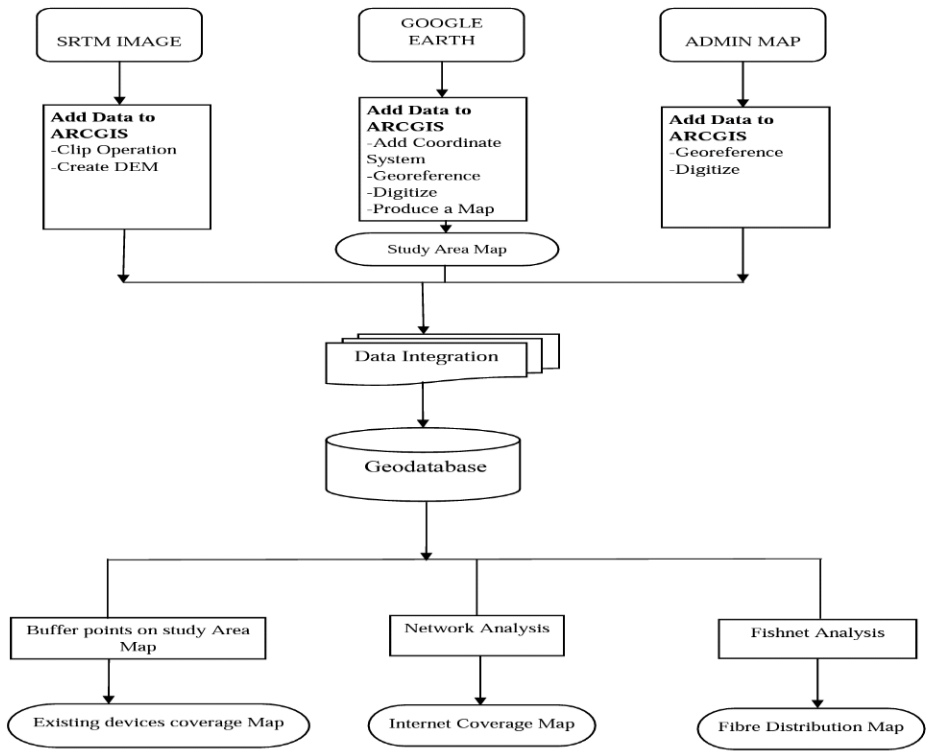

Figure 3.1: Flow Chart of the Research

Data collected included image of the study area downloaded from Google Earth Pro, administrative map of Tanzania downloaded from the website:

https://www.nationsonline.org/oneworld/map/tanzania-administrative-map.htm Software used for analysis were ERDAS Imagine 15, ArcGIS 10.7.1, Microsoft Office Suites 2013 (Excel and Word) and Google Earth Pro. Other data sources are displayed in Table 3.1.

Table 3.1: Data Sources

Serial No.	Data	Source
1	Admin Maps	https://www.nationsonline.org/oneworld/map/tanzania-administrative-map.htm
2	Study Area Image	http://www.earthgoogle.org
3	GPS Points	http://www.earthgoogle.org
4	Digital Elevation Model Data	https://www.gisgeography.com/free-global-dem-data-sources/ https://www.1pdaac.usgs.gov/product_search/ https://www.e4ftI0!.cr.usgs.gov/ASTT/ https://www.gdemdl.aster.jspacesystems.or.jp/indexen.html

Data Processing

The downloaded Digital Elevation Data Model from www.gdemdl.aster.jspacesystems.or.jp/index_en.html was added to Arcmap 10.7.1. Clip operation was performed to obtain the DEM for the study area.

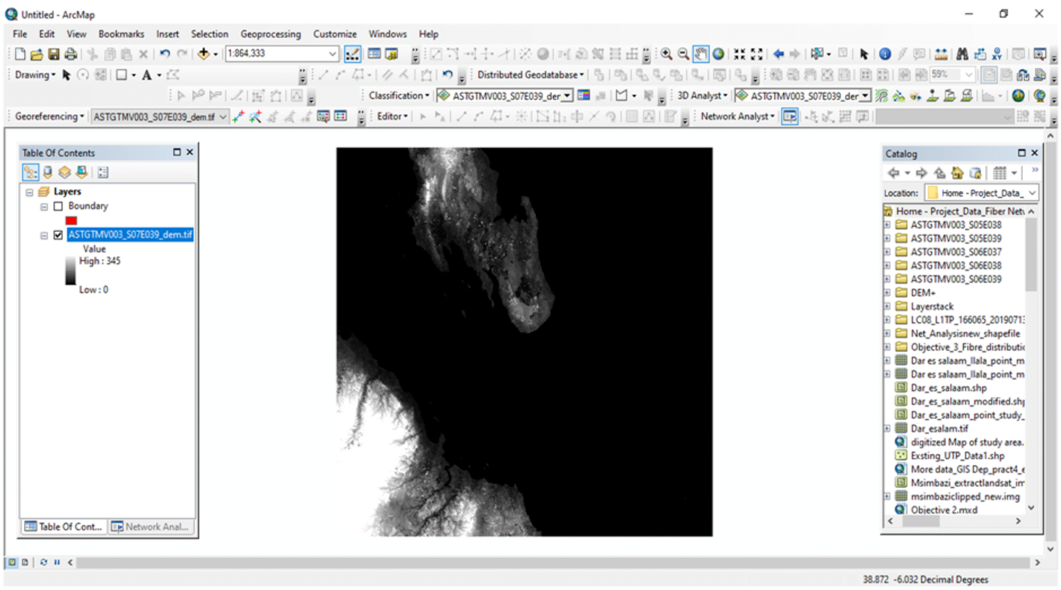

Figure 3.2: Digital Elevation Model Data of the study area

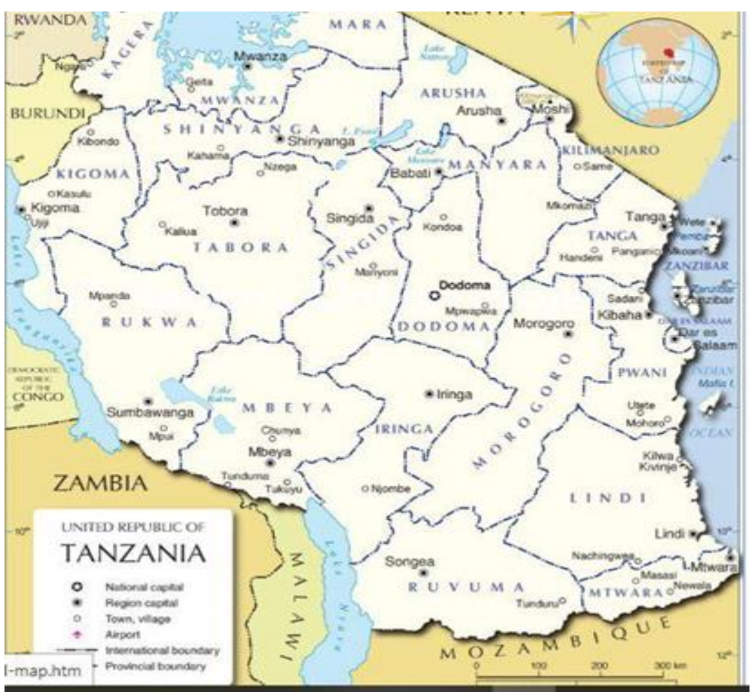

Figure 3.3: Administrative Map of Tanzania
(https://www.nationsonline.org/oneworld/map/tanzania-administrative-map.htm)

The downloaded administrative map (Figure 3.3) was referenced based on World Geodetic System 1984 (WGS 84). The topographic map was digitized with ArcMap Map 10.7.1 to create 26 regions (Figure 3.4).

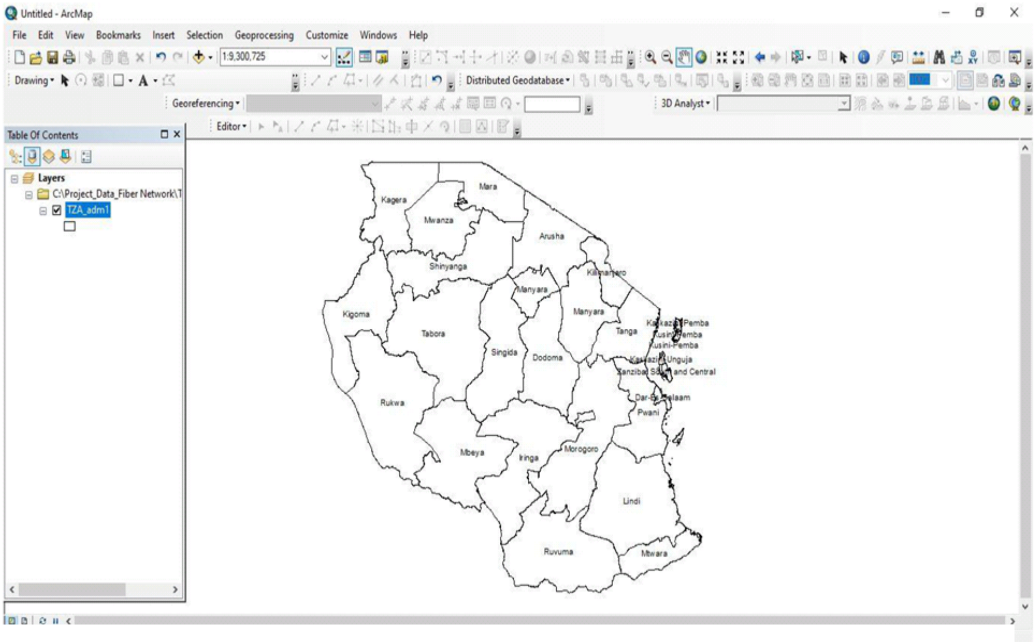

Figure 3.4: Digitized Administrative Map of Tanzania

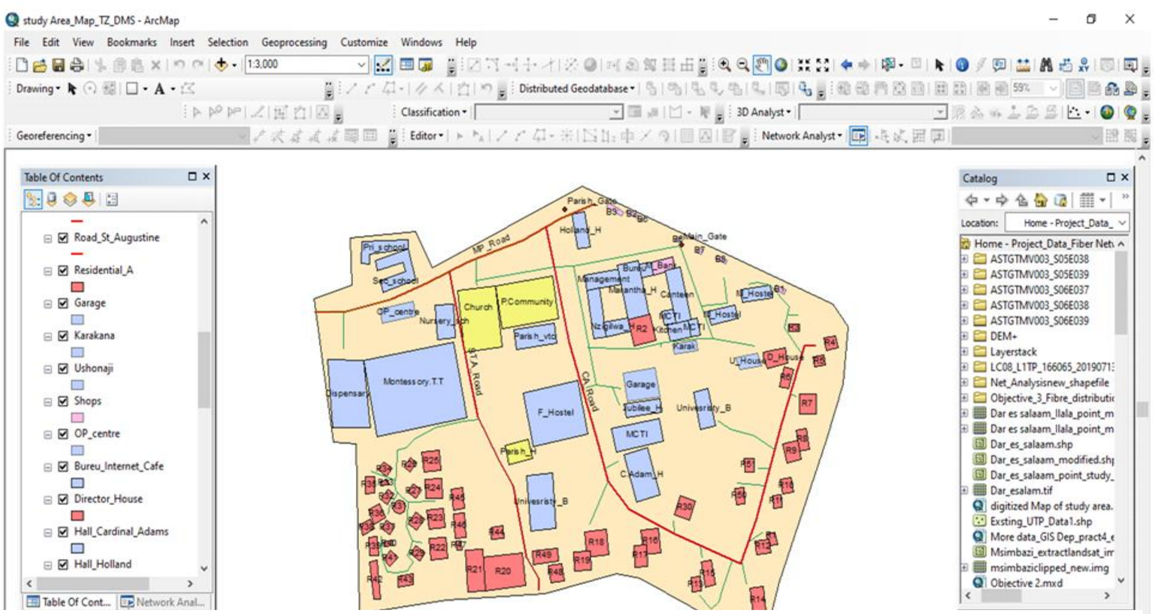

Figure 3.5: Digitized Map of Centre for Religious Education and Social Services of the Archdiocese of Dar es Salaam

The downloaded Google Earth image was georeferenced, then a personal geo-database as created and the image digitized to obtain the digitized map of the study area (Figure 3.5).

The data obtained from the DEM, Digitized Administrative map and Digitized study area map were stored in a geodatabase in ArcGIS 10.7.1 for analysis and discussion. Network analysis was performed to identify the New Routes and coverage area in the study area. The area was buffered at 20m, 30m, 40m and 50m to identify the number of users covered in the proposed Fibre optic network. The GPS locations of the connected devices were established and then measured to show the coverage distance of each device in the study area within 20m, 30m, 40m and 50m radii respectively.

The DEM image obtained from www.gdemdl.aster.jspacesystems.or.jp/index_en.html/ was overlaid on the study area map to identify the areas with low elevation while Fishnet Analysis was carried out to locate suitable routes. Network analysis was done to identify the new route and new services coverage in the study area. Different buffers at 20m, 30m, 40m and 50m respectively were created on the suitable route junctions to identify the number of users to be covered by the proposed Fibre optic technology.

RESULTS AND DISCUSSION

Internet Connection Coverage Area of the Existing Unshielded Twisted Pair Devices in the Study Area

Figure 4.1 shows the existing Internet coverage of the Centre for Religious Education and Social Service of the Archdiocese of Dar es Salaam. The devices at each location were identified to include Router with 300mbps speed, Switch with 10/100 mbps speed, and Modem of 56 Kbps speed. GPS coordinates of each location were buffered at 50m to determine the coverage of each device. The results revealed that areas within 50 meters had the most device coverage while the areas above 50 meters had the least or no device coverage contingent on the signal strength of connected device, corroborating the limitations highlighted in the maintenance reports (Msimbazi Centre, 2019), showing that UTP coverage diminishes significantly beyond 50 meters, particularly in areas with high user density e.g. hostels, administrative offices.

Internet coverage area of the existing UTP connections

Network analysis assessment was performed on the study area map to determine the coverage distance of the existing UTP internet connection. Different radii of 20m, 30m, 40m, and 50m respectively were created to determine existing coverage of the service area as shown in (Figure 4.2) and further explained in (Table 4.1). This agrees with (Pigg, 2004) that UTP cables has short signal boosts, thus making them less effective for wider spatial coverage. The result revealed coverage area to be 35.71% while 64.29% of the total study area remained underserved, mainly due to the limitations of UTP cables, especially in long-distance signal propagation. These findings align with Ronnie (2020) and Dinc et al. (2021) who emphasized the susceptibility of UTP cables to electromagnetic interference (EMI), which likely contributed to weak and inconsistent connectivity in the study area. Thus, the results validate existing knowledge on UTP's technical constraints and demonstrate the real-world impact of these limitations in institutions with expanding digital needs (Kowero, 2012).

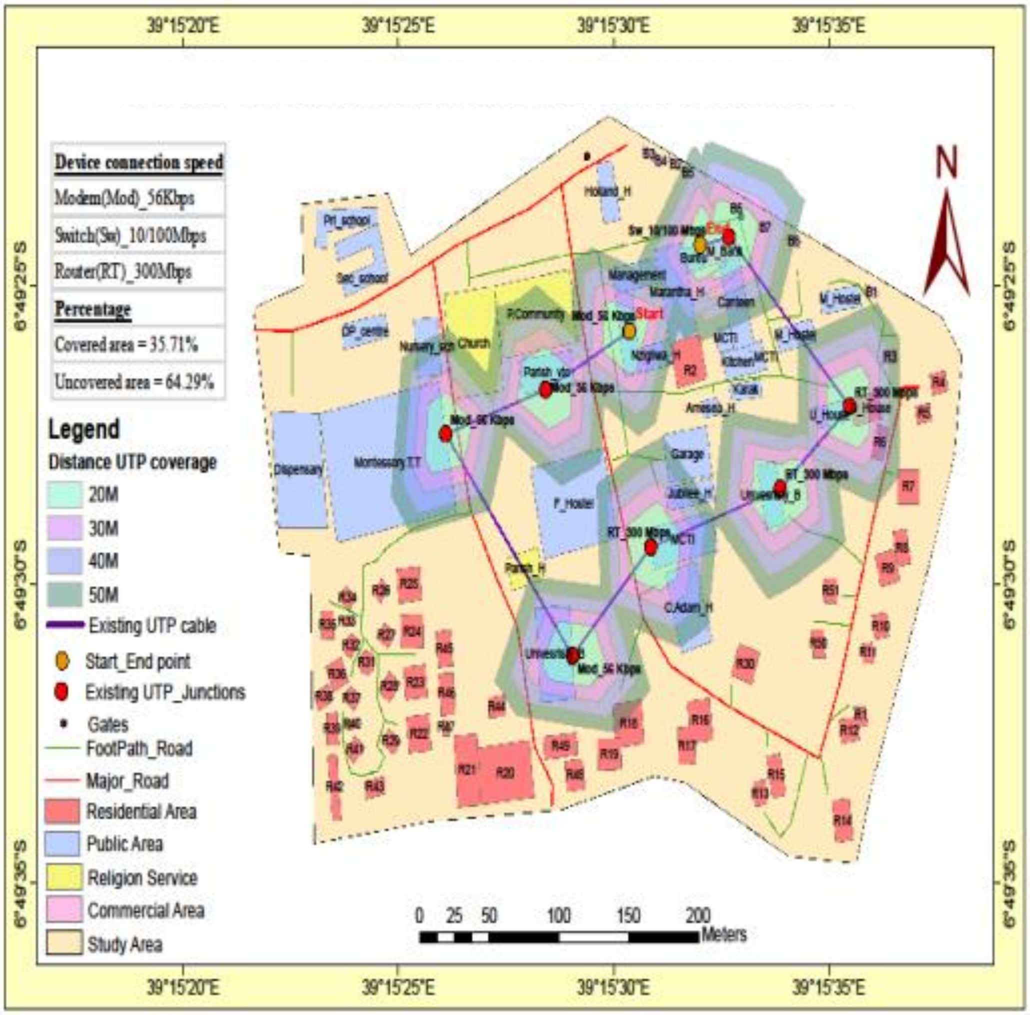

Figure 4.2: Existing UTP technology internet coverage (Authors' Field Survey)

Table 4.1: Existing UTP Internet Coverage of the Study Area

FID	Name	X	Y	Status	Activity	Buffer Dist. (m)	No_Users	Device
0	Management	39.258	-6.824	Existing	Public	50	15	Mod_56 Kbps
1	Parish_Vtc	39.258	-6.824	Existing	Public	50	53	Mod_56 Kbps
2	MCTI_AE	39.259	-6.825	Existing	Public	50	191	RT. 300 Mbps
3	Montessory T. T.	39.257	-6.824	Existing	Public	50	61	Mod_56 Kbps
4	University_C	39.259	-6.825	Existing	Public	50	53	RT. 300 Mbps
5	University_O	39.258	-6.825	Existing	Public	50	25	Mod_56 Kbps
6	D.House	39.260	-6.824	Existing	Public	50	5	RT.300 Mbps
7	M_Bank	39.259	-6.823	Existing	Commercial	50	20	Mod_56 Kbps
8	Bureau	39.259	-6.823	Existing	Public	50	20	Sw.10/100 Mod_56 Mbps

Proposed Fibre Optic Coverage Map

Using GIS-based fishnet analysis, DEM overlays, and network analysis, the study identified optimal routes for deploying fibre optic cables, balancing topographic suitability and user coverage. The proposed design offered complete internet coverage within the Centre and strategic placement of backbone and drop cables to ensure equitable and scalable internet access.

New Service area network analysis was performed in different breaks from 20m, 30m, 40m and 50 meters to show the coverage area for the proposed Fibre optic distribution.
The results revealed the complete coverage of the proposed Fibre optic deployments in the study area. Figure 4.3 and Table 4.2 show the proposed Fibre optic technology coverage map. These results align strongly with prior research by Pedersen et al. (2010) and Omogunloye et al. (2013), who emphasized the value of terrain-informed, GIS-driven network planning for efficient fibre optic deployment. Similarly, Ramaswami & Sivarajan (2002) and Pazi & Chatwin (2013) highlighted fibre optic's capacity for higher bandwidth, security, and longevity, which the proposed network seeks to leverage.

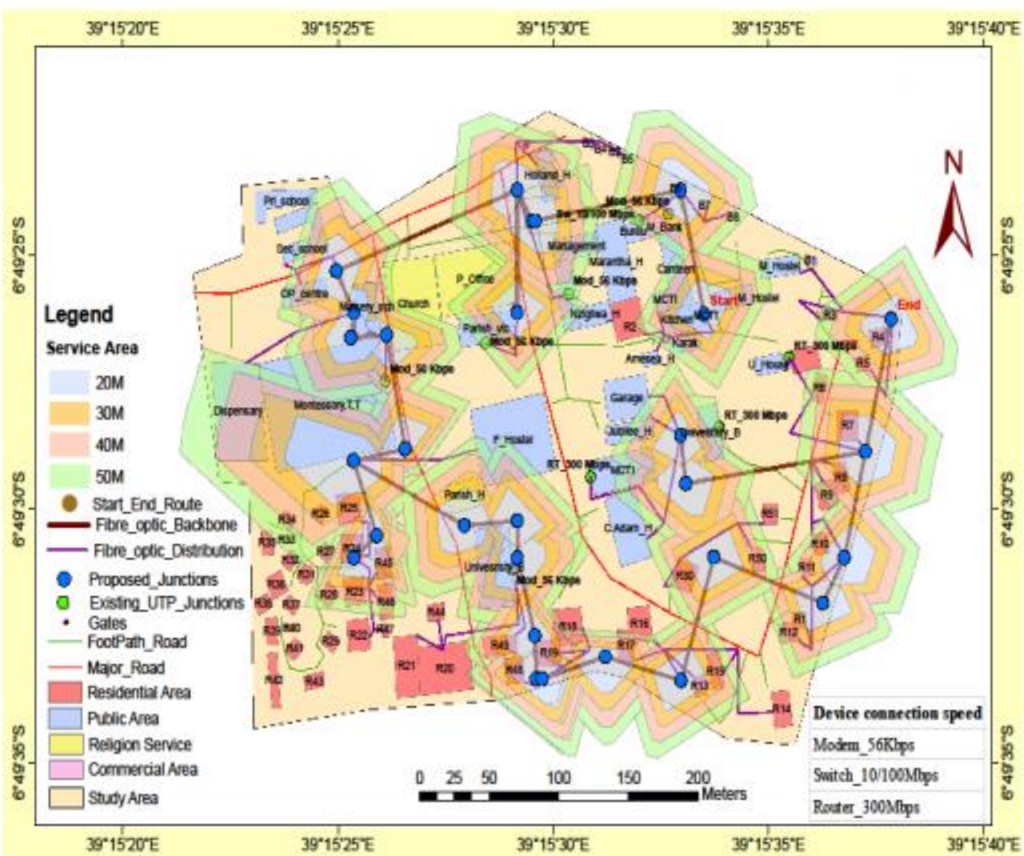

Figure 4.3: Proposed Fibre Optic Technology Coverage Map of the Study Area

Table 4.2: Proposed Fibre Optic Network Coverage

FID	Name	X	Y	Status	Activity	Buffer_Dist (m)	No_Users
0	R48	39.258	-6.826	Proposed	Residential	60	10
1	R13	39.259	-6.826	Proposed	Residential	50	10
2	R24	39.257	-6.825	Proposed	Residential	70	22
3	University_O	39.258	-6.825	Proposed	Public	20	25
4	R30	39.259	-6.825	Proposed	Residential	30	8
5	R10	39.26	-6.825	Proposed	Residential	60	16
6	Montessory T. T.	39.257	-6.825	Proposed	Public	70	61
7	University_C	39.259	-6.825	Proposed	Public	20	244
8	R7	39.26	-6.825	Proposed	Residential	60	10
9	Nursery_Sch	39.257	-6.824	Proposed	Public	20	70
10	Parish_Vtc	39.258	-6.824	Proposed	Public	60	53
11	MCTI_HM	39.259	-6.824	Proposed	Public	30	45
12	R3	39.26	-6.824	Proposed	Residential	50	10
13	Holland_H	39.258	-6.823	Proposed	Public	60	8
14	B6	39.259	-6.823	Proposed	Residential	60	12

The incorporation of DEM in route planning addressed terrain variations that could affect installation logistics. The identification of low elevation zones helped minimize trenching difficulties and potential physical damage to cables from runoff or erosion. This agrees with the conclusion of Anderson (2019) and National Geo (2017), who stress that terrain-aware planning via GIS not only improves operational efficiency but also reduces cost and infrastructure risks. The use of buffer radii (20m, 30m, 40m, 50m) around access points to simulate signal reach under the proposed design is a practical, quantifiable metric for coverage simulation. It also provides a replicable approach for other institutions facing similar connectivity issues.

The results concretely show that fibre optic ensures near-complete coverage of the study area with minimal infrastructure changes, less prone to interference and supports longer distances without degradation. It further shows that fibre optic offers a sustainable infrastructure investment with a lifespan of 30–50 years (Kowero, 2012; Biswas, 2017).

The proposed shift from UTP to fibre optic thus represents a strategic technological leap that mirrors global digital infrastructure trends, echoing the observations of Thakur (2021) and Fibre Optics Association (2014).

CONCLUSION

The study successfully demonstrated the application of remote sensing and GIS techniques as supportive tools in the effective proposition of fibre optic network infrastructure to ensure complete coverage of internet connection in the Centre for Religious Education and Social Service of the Archdiocese of Dar es Salaam.

By integrating DEM-based terrain, fishnet and network analyses, a thorough routing of Fibre optic technology was proposed. The findings highlighted the limitations of existing UTP connections and offered a scalable solution for complete network coverage.

The proposed fibre optic deployment significantly enhances coverage and reliability, establishing a benchmark for future network planning in similar scenarios. These results underscore (National Geo, 2017), that the critical role of geospatial technologies in making informed decisions for infrastructure development, especially in areas with limited connectivity.

The study recommends replacing obsolete technology with robust alternatives by suggesting the substitution of UTP devices with Fibre optic technology in order to raise the band width, minimize signal loss and enhance the network. The deployment of the proposed network should focus on underserved areas as identified in the analysis with the goal of providing high-speed internet to all users.

Proper network planning is imperative for effective use of the new infrastructure thus geospatial approaches like network analysis and Digital Elevation Model (DEM) are recommended to identify suitable routes for deployment of fibre optic backbones and drop cables. This approach not only minimizes environmental destruction but also deployment costs which makes the project economically viable. Increasing the number of routers and switches to more strategic junctions in order to expand the number of users especially in far reaching areas that are currently not connected by the network is also recommended. The 50-meter radius which is currently the acceptable reach for the network should be extended to greatly improve service reach.

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