Telemedicine as a panacea to medical tourism in Africa: Exploiting communication satellite technologies

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List of Abbreviations

AWS	Amazon Web Services
BCDA	Border Communities Development Agency
CME	Complex Medical Engineering
CP	Conference Proceedings
DFH-4	Dong Fang Hong-4 Satellite Bus
ECG	Electrocardiogram
EGNOS	European Geostationary Navigation Overlay Services
ESA	European Space Agency
FAAN	Federal Airport Authority of Nigeria
GUI	Graphic User Interface
HiPAA	Health Insurance Portability and Accountability Act
ICECCME	International Conference on Electrical, Computer, Communications and Mechatronics Engineering
ICOM	International Conference on Mechatronics Engineering
ICT	Information and Communications Technology
IDP	Internally Displaced Persons
IEEE	Institute of Electrical and Electronics Engineers
ISP	Internet Service Providers
JETM	Journal of Engineering and Technology Management
LEP	Limited English Proficiency

NEMA	National Emergency Management Agency
NASRDA	National Space Research and Development Agency
NIGCOMSAT	Nigerian Communications Satellite
NIHR	National Institute for Health and Care Research
NNBP	Nigerian National Broadband Plan
NOS	Navigation Overlay Service
OMT	Orthogonal Mode Transducer
P2P	Peer-to-Peer
PHR	Personal Health Record
S4DH	Satellite For Digital Health
SDG	Sustainable Development Goals
SMS	Short Message Services
VSAT	Very Small Aperture Terminal
XMPP	Extensible Messaging and Presence

1. Executive Summary

Nigeria's health service struggles with a brain drain, insufficient infrastructure and inadequate specialist skills with affluent patients choosing to be treated outside the country. Thus, medical tourism is costing the Nigerian economy approximately $1.3 billion annually. Hence, the health service for dependent Nigerians, in particular those living in rural and remote areas, is often poor and inadequate. This research project draws on a mixed methodology approach comprising of case studies, a survey and action research to examine and determine the resilience of communications satellite technology to provide telemedicine services to improve access to high quality healthcare advice and services in rural areas as well as explore and create a mobile emergency response facility that can be quickly deployed to a disaster location or to Internally Displaced Persons (IDP) camps. It was also an attempt to enhance the nation's disaster response preparedness and effectiveness utilizing communications satellite technology and software applications. Key Research Findings and outcomes are as follows:

i) A total of 766 patients had medical consultations during the Connect2Recover (C2R) medical outreach and program.

ii) 81.8 percent of the patients and medical personnel who participated in a survey strongly agreed that the One2One mHealth Telemedicine Services vis VSAT-based Internet provided an acceptable way to locally deliver healthcare services and reduce medical tourism from rural area to urban centers including outside the shores.

iii) The One2one mHealth application has been made available freely on google store.

iv) Communications Satellite Networks can provide the required broadband bandwidth for effective delivery of telemedicine services in areas with little or no terrestrial mobile networks to fast track Sustainable Development Goal 3 on health. Robust networks requires taking into account equipment sizing from gateway of the teleport to the end user equipment for delivery of efficient broadband services end-to-end.

v) Major challenges facing the adoption of telemedicine in Nigeria are language barriers and the low literacy level of the population, especially in underserved communities. A sustainable solution to this issue is the use of support staff to bridge the gap between the digital approach to health care delivery and the low literacy level of the population.

vi) The video call feature of the One2One mobile application was essential for the purpose of physical examination, especially in the case of visible skin conditions. This feature is, therefore, strongly recommended for any software developed for providing telemedicine services.

vii) The low doctor-patient ratio across Nigeria has been identified as a cause of poor services in the healthcare sector. The availability of multiple doctors on

the One2One application increased the doctor-patient ratio and made it possible for five patients to be attended to concurrently.

Healthcare reform that encourages innovation and policy recommendations on the delivery of local health-care system and health insurance coverage for poor Nigerians would contribute towards meeting United Nations Sustainable Development Goals, in particular, Goal 3 on Good Health and Well-being by 2030.

Some of key recommendations based on survey, case studies and action research under the six –months research program are:

i. Mobile health applications with audio, video, and text capabilities can be leveraged as a tool to provide telemedicine services in cities, urban areas where broadband mobile networks are available and through Communications Satellite in areas with little or no terrestrial networks especially inhabitants of rural communities to fast track United Nations Sustainable Development Goal 3 to ensuring healthy lives and promote well-being for all at all ages while equally checking medical tourism in Nigeria. Language translation features can be incorporated into such mobile applications to bridge the language and literacy gaps in rural communities.
ii. Telemedicine can only work efficiently with sufficient broadband bandwidth. Communications satellite networks should take account of end-to-end networks with appropriate traffic engineering with link budget analysis to ensure robust and resilient network connectivity for telemedicine services. It is a viable option for providing Telemedicine in rural and underserved communities of Africa.
iii. Sensitizing the public on the benefits of adopting digital health especially in University Teaching Hospitals and other related health organizations will increase its acceptance rate and adoption in the country.

2. Introduction

This report with research project titled “Tele-medicine as a Panacea to Medical Tourism in Africa exploiting Communication Satellite Technologies” was one of the winning proposals in the international research competition organized by the International Telecommunication Union’s (ITU) Connect2Recover initiative; the first ever international research competition organised by the ITU. The competition which received 307 entries from 80 countries across the five continents had 15 outstanding winners which includes our research project.

As background, Connect2Recover is an ITU global initiative that aims to reinforce digital infrastructure and ecosystems of beneficiary countries. The initiative seeks to galvanize action for affordable and reliable connectivity as part of COVID-19 recovery strategies and also assesses risks due to natural hazards in strengthening resilience of digital infrastructure. Further, the research competition involved identification of research proposals that have potential in fostering digital inclusion and digital resilience during the global recovery; specifically in the key areas of education, jobs and healthcare.

This research project was selected and the winning team include: principal Investigator, Engr. Dr. Lasisi Salami LAWAL (CEng) as principal investigator with twelve (12) other participants as co-investigators, collaborators and supervisors as outlined below:

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xi. **Dr. Abimbola Alale** (Supervisor); Managing Director and Chief Executive Officer of Nigerian Communications Satellite Ltd.

xii. **Professor Mohammed Nasir Sambo** (Supervisor); Professor of Health Policy and Management with Bias for Health Care Financing and Keen Interest in Digital Technology for Health Systems, Executive Secretary of The National Health Insurance Scheme (NHIS).

xiii. **Prof. Isa Ali Ibrahim (Pantami),** (Supervisor); Professor of Cyber Security, Federal University of Technology, Owerri and Honorable Minister of Communications and Digital Economy of Federal Republic of Nigeria.

2.1 Research Background

Medical tourism refers to people traveling outside the shores of their country to obtain medical treatment that are unavailable at home. Nigeria loses over $1.3 billion to medical tourism annually, which represents a huge capital flight and becomes a burden to the nation's economy and GDP. The cause of medical tourism in Nigeria is due to inadequate and low-quality medical healthcare facilities. This has led to the current thriving medical tourism in countries like the United Kingdom, United States of America (USA), Germany, India, Canada, France, Turkey, Malaysia, Singapore, China, and Saudi Arabia. At a time before the dawn of COVID-19, it was reported that almost 5,000 people in Nigeria leave the country monthly for various forms of ailments and treatments abroad, but the number has reduced drastically since 2020 due to the outbreak of the COVID-19 pandemic with travel restrictions.

Globally, medical tourism has contributed immensely to the growth and development of healthcare system and countries engaged in it because it attracts people from various parts of the world, thereby adding value to the countries involved. In the United States for example, over 60,000 medical tourists were attracted to the country in 2008, while in the year 2012, Jordan attracted 250,000 international patients accompanied by more than 500,000 relatives generating well above $1 billion in income from medical tourism that same year [17]. There is no record of medical tourists coming to Nigeria as compared to the glorious past of Nigeria in the 1970's when the nation had good healthcare facilities and personnel in the premier teaching hospital of the University of Ibadan and other teaching hospitals. As a result of poor remuneration for healthcare professionals, there is a brain drain resulting in poor service delivery, poor funding, unavailability of human capital, poor infrastructure, and an absence of specialist services.

High quality healthcare service delivery is not available in rural and semi-rural areas of the country as medical professionals prefer to live and work in urban centres with modern facilities and city-wide infrastructure.

The project and case study examined the application and resiliency of communications satellite technology to provide tele-medicine services for the following: improvement of access to high quality healthcare services, reduction of deaths per 1000 through

early diagnosis and prompt treatment, as well as leveraging specialist and teaching hospitals to enhance and improve sustainable healthcare services.

There has always been a disparity in access to basic infrastructure between those who live in urban centres and those in rural areas. This imbalance is now more evident with ICT infrastructure because of the increasing role that ICT applications play in the commercial and domestic sectors. The COVID-19 pandemic has amplified this imbalance, with those living in rural areas not being able to even access online self-help services.

When the international community met at the United Nations Millennium Summit in 2000, they adopted the Millennium Declaration which recognizes: “the wide consensus that information and communication technologies are central to the creation of the emerging global knowledge-based economy and can play an important role in accelerating growth, in promoting sustainable development and eradicating poverty in developing countries as well as countries with economies in transition and in facilitating their effective integration into the global economy”[9].

The challenges facing rural areas in Nigeria are enormous and the digital divide in Africa is still huge but African leaders and stakeholders have recognized the many challenges that confront their countries and are addressing them with adventurous development programs. For instance, the Nigerian National Broadband Plan (NNBP) 2020 to 2025 identified unserved areas and access gaps in the nation and invested in enabling alternative technologies i.e., communications satellites to foster and consolidate broadband penetration and open up the economy to deliver the sustainable development goals for rapid attainment of agenda 2030 with the support of the private sector and international investors.

Nigeria’s communications satellite is responsible for some initiatives of the NNBP 2020- 2025 as National Satellite Broadband Deployment is expected to support the development of Nigeria’s Digital Economy. Accordingly, communications satellites will be used to deploy broadband/Internet services up to 10Mbps per site to over 3,000 cluster groups: providing connectivity to schools, community telecentres, and hospitals in the difficult-to-reach areas. They are to be used to provide mobile backhaul solutions up to 15Mbps per site for 700 rural base transceiver station (BTS) sites for the coverage of the difficult-to-reach areas.

Furthermore, border communities are expected to receive specific funding from the Border Communities Development Agency (BCDA) in compliance with the government’s remote community’s development plans for border broadband intervention (within 1-2Km distance from all border posts). The strategic plan provides an extraordinary opportunity to promote telemedicine and e-health for acceptance and adoption, especially in targeted rural areas where the impact will be high with the primary objective to accelerate broadband penetration to the rural and difficult-to-reach areas and ensure a rapid and even spread. This project was focused on the deployment of digital health using communications satellites enabling shared specialist personnel through the one2one health app that resides in Nigerian central

health facilities and elsewhere to the underserved in Nigeria.These underserved communities include IDP camps, remote villages, communities with minority populations, disaster-affected areas, etc.

2.2 Research Scope

The scope of the project was limited to deploying digital health care services using communications satellites for the underserved communities in Nigeria. The deployment of this health care service took place in three (3) states (Kaduna, Abuja and Akwa Ibom) representing Northern, Central and Southern regions of Nigeria within a six (6) month period.

2.3 Research Objectives/Aim

The aim of the project is to promote and improve access to high-quality healthcare services through communications satellites, as improved health could lead to improvement in livelihood and socio-economic development of the people.
The objectives to achieving this aim include:

i. Implement a robust network design to exploit the application of communications satellite to deliver broadband for telemedicine to designated pilot clinical sites and IDP camps in Nigeria.
ii. Evaluate the acceptability, utility and adoption of VSAT-based telemedicine delivered using peer-to-peer eHealth app (One2one Healthcare Application).
iii. Publication of research results in conference proceedings (CP) and refereed journal.
iv. Propose recommendations to relevant authorities on VSAT-based telemedicine research findings as part of National ICT strategy, policy and recommendations to drive digital health inclusion in Nigeria and Africa, in general.

3. Literature Review

3.1 A Review of Telemedicine

The continued impact of COVID-19 in Nigeria on public health, social welfare, economic activities and healthcare makes it imperative that we deploy ICT infrastructure and most especially space-based technology-driven telemedicine to enhance remote access to medical professionals, specialists and expert consultation for rural and unserved areas in Nigeria.

The adoption of telemedicine since the COVID-19 pandemic has massively increased [1] because telemedicine provides a means to access medical personnel without direct physical contact [2] - a major advantage considering the mode of spread of the SARS-CoV-2 virus. However, in most countries across Africa, including Nigeria, its acceptance and adoption rates are still low [3]. Although many pivotal telemedicine projects have been adopted in Nigeria in recent times with successful outcomes [4],

individuals, as well as medical personnel still doubt the efficacy of telemedicine and are unwilling to adopt it [5].

A typical example of a telemedicine application is how it can be employed by a person with diabetes. The individual could make use of a mobile application to estimate the body's insulin needs based on the level of physical activity. The individual could also schedule doctor's appointments via an online health portal, or receive reminders via texts or emails at the scheduled time for foot examinations. Other possibilities include the use of a smartphone to take retinal photos to be sent electronically to a specialist, or the use of a mobile phone to upload vital signs to a nurse who responds electronically [6].

The main goal for the establishment of telemedicine programmes was to provide healthcare access to individuals in remote locations, like soldiers at the war front, astronauts in space, or workers on oil rigs. However, over the years, its applications have been extended. The increase in its popularity was greatly enhanced by the recent COVID-19 pandemic, which enforced mandatory social distancing, making telemedicine the safest interactive system between medical practitioners and patients [7].

The recent global practice of telemedicine involves the following:

i. Presence of fast and reliable internet access at both ends for effective communication [8].

ii. The use of online patient portals by clinics as an alternative to emails, as portals are a more secure means of communicating private medical information. Patients can use the portals to communicate with doctors, request refills of medication, schedule appointments, and review test results [6].

iii. The scheduling of virtual appointments with doctors and nurses via videoconferencing, in a way that imitates the services at a drop-in clinic. The patient is usually required to answer a series of questions on a website, after which a doctor can prescribe medications or recommend additional medical care [6].

iv. Remote monitoring of patients using mobile or web-based applications. The applications are used to upload information such as patients' vital signs to a doctor or health care team. Some of the devices used, such as heart rate monitors, can wirelessly transmit information and detect changes in normal activities [6].

v. Virtual consultation between doctors to reduce waiting time to see specialists and eliminate unnecessary medical tourism. The primary care doctor sends patient history, test results, notes, and images to the specialist, who may conduct a virtual appointment or request a physical meeting [6].

vi. The use of electronic personal health record systems (PHR systems). A PHR system is a digital record of health information that can be updated and maintained. It

is usually accessible only to authorized personnel via web-enabled devices such as computers or smartphones. In an emergency, health care personnel can quickly retrieve vital patient information, such as pre-existing medical conditions, allergies, and the contact information of the patient's doctor with secured end-to-end security [6], in line with the Health Insurance Portability and Accountability Act of 1996 (HiPAA) guidelines; a law that required the creation of national standards to protect sensitive patient health information from being disclosed without the patient's consent or knowledge [9].

vii. The use of personal health applications by patients to record vital signs, set reminders for medication, calculate calorie intake, store health information, or record physical activity. The main aim of these applications is to help consumers organize their health information in one secure place [6].

viii. The hosting hospital or clinic should be well equipped with digital examination equipment, such as digital stethoscopes, ECG monitors, and otoscopes [8].

ix. The use of virtual reality (VR) has been proposed recently as an innovative means to implement treatments in a wide range of clinical areas, including cognitive rehabilitation, anxiety disorders, depression, schizophrenia, eating disorders, pain management, and motor rehabilitation. Virtual reality involves the interaction with, and immersion into a computer-generated environment in a realistic way. This approach to rehabilitation offers several advantages over the traditional approach. For example, it allows for the transfer of skills from the virtual to the real world, as a result of the intuitive interaction between the user and the computer-generated environment. It also offers instant and direct feedback, so that the degree of difficulty of therapy can be easily tailored to the patient's needs and the acuteness of their condition [10].

The COVID-19 pandemic has presented new challenges to public health and medical care delivery. As a means to control its transmission, social distancing measures were implemented across the globe, limiting customary access to medical care for many individuals [10]. Therefore, it is no surprise that one of the major changes implemented globally in response to the pandemic has been the high-speed expansion of telemedicine [1].

For underserved populations, telecare services are often less accessible. Such populations include ethnic or racial minorities, people living in rural areas, and those with low income, limited English proficiency (LEP), or low literacy [11]. The underserved populations that stand to benefit the most from telemedicine-enabled care are the same ones who lack access to the technology required to benefit from it [12, 13]. This deficiency of health care access among the underserved has been emphasized by the COVID-19 pandemic. Though the overall adoption of telemedicine increased significantly after the onset of the pandemic, the adoption among those with limited healthcare and digital access decreased [14]. This presents implications for the adoption and growth of telemedicine in countries with large technology gaps. In Italy,

for example, where a major contributor to the spread of COVID-19 was thought to be hospital transmission, the use of telemedicine to minimize physical visits to hospitals was hampered by a limited telecommunications infrastructure [15]. These challenges are even more pronounced in low- and middle-income countries in Africa and Latin America [3].

3.2 Digital Health Inclusion in Nigeria

The introduction of digital health into the healthcare system/health sector was aimed at achieving some particular objectives. These objectives will serve as instruments for tracking the progress in its implementation. Some of the objectives include: reduction in the number of people traveling outside the shores of Nigeria to obtain medical treatment, improvement in the quality of care, improving access to healthcare, lowering the cost of healthcare, improving the patient experience, providing more personalized health care for patients, curbing any inefficiency in the healthcare system and enhancing the physician and other non-physician provider experience.

Furthermore, the advantages of this development may include but are not limited to: lowered healthcare cost, increased service quality, promoted digital economy, enabled personalized healthcare system, prevented the spread of infectious diseases, eased access to healthcare without barriers or limitations, eased access to patients' records for proper follow-up, and updated database information for tracking healthcare delivery improvement.

A large number of African countries cannot deliver elementary provisions for efficient and stable healthcare systems, resulting in chaotic healthcare services. Unfavourable governance and poor management of resources also contribute to chaotic services in resource-constrained countries. The parlous state of the health care system has positively impacted medical tourism, causing over five thousand persons to embark on medical tours monthly. This has led to an estimated annual loss of 1.2 billion US dollars by the Nigerian economy to medical tourism annually [16].

4. Methodology

The research and deployment of the health care services in Nigeria for this report were classified in three categories which are:

i. Case study
ii. Survey
iii. Action research

4.1 Case Study

This involved an intense review of papers on telemedicine, satellite communications and digital health. Investigation and assessment of industry standards and communications satellite technologies for telemedicine including existing telemedicine projects and programs. Projects such as the European Space Agency (ESA) funded project and research on specific procedures and techniques focusing on validation and reliability. The specific procedures and techniques includes to identify, select, process, and analyse information for a sustainable pilot project design in African countries for the post-COVID-19 era, where people are having to deal with long-term consequences of COVID-19.

Firstly, previous case study of telemedicine projects were reviewed and followed by based on Ethical Application request from Imo State University Teaching Hospital which was approved on 25th January, 2022, and this signals the commencement of field trials after a series of evaluations and tests. In addition, familiarization visits were made to an IDP camp to gain first-hand knowledge and experience of the services provided by the numerous Non-Government Organizations (NGOs) to the vulnerable citizens in the camp.

Secondly, we visited the University of Uyo Teaching Hospital in Akwa Ibom State to survey their facilities and to gain an understanding of their telemedicine practice. We collaborated with their Medical Personnel (both those in training and postgraduate students) to carry out three (3) days telemedicine medical outreach at a cottage Hospital in Ikot Ekpene Udo; Nsit Ubium Local Government Area within the vicinity of Akwa Ibom State. This outreach exposed them to telemedicine experience, and provides an opportunity for future collaboration.

Thirdly, a telemedicine pilot project which was handled in the past by the National Space Research and Development Agency (NASRDA) in Nigeria was studied. The project involved linking a major hospital to distant centres for the provision of clinical services, medical education, research and diagnosis, thereby enabling teams of medical experts to undertake cross-consultation and obtain second opinions on any case handled between themselves without physically moving from their locality. NASRDA achieved success in this field by partnering with the Ministry of Health to link up six teaching hospitals in six geo-political regions of the country using the Ku- band of NIGCOMSAT-1R using a Hughes Hub. Some lessons were learned from the pilot project, which includes but is not limited to, sustainability issues especially as it concerns recurrent bandwidth requirements for connectivity, maintenance and servicing of devices and equipment.

This was followed by a trip to Nairobi to attend Newspace Conference to explore new satellite kits for telemedicine, which led to trial of use of the Kyemeta U7 Terminal Flat Panel Mobile Antenna that was rented and utilized for the medical outreach to ascertain its robustness with our one-to-one telemedicine application. We also attended the first ITU WTDC hosted in Africa at Kigali, Rwanda to connect, update and collaborate including participating in the Partner2Connect initiative.

We also attended the Kenya Space Agency Conference and Exposition 2022 with the theme “Leveraging Space Capabilities for National Development”, where we shared thoughts on the use of satellite communications in Africa to extend health services to people in rural and unserved areas including the provision of specialist health services via digital health application to reduce medical tourism in the continent. The comprehensive study and review of telemedicine led to the production of one of our manuscript paper titled “A Review of Telemedicine and its Potential in Developing Countries” which was submitted to the 8th International Conference on Mechatronics Engineering (ICOM’22). Notification of acceptance of the paper was communicated on 30th June, 2022, and we registered for virtual participation in the Conference that is scheduled from 9th to 10th of August, 2022 at Kuala Lumpur, Malaysia.
Another manuscript paper that is being considered for submission in a journal is titled “Internally Displaced Persons (IDPs) in Nigeria: An Overview of Health Situation”.

4.2 Survey

Interviews, consultations and discussions with stakeholders with diverse perspectives including: relevant companies in healthcare technologies; virtual consultations with Project team heads on a Telemedicine pilot in Europe, Canada, United Kingdom including overseas health institutions that are practising telehealth, e-health and/or telemedicine; the school convener, School of Engineering Design and Informatics, University of Sussex, Brighton; Professor of Global Health Epidemiology, NIHR Global Health Research Programme Training Steering Group Brighton and Sussex Medical School, professional colleagues; specialist hospitals; and a rural medical clinic. In addition, in the course of our medical outreach, a survey was conducted using paper questionnaires to determine the usability of the One2One mobile application, which was the tool used for communication between patients and doctors in various parts of the world. The details of the questionnaire used are as provided in Appendix M1, M2, M3, M4, M5 and M6. The Appendices are: on consent for participation, study of socio demography of patients, interview guide for healthcare providers and administrators, Interview Guide for Patients, mHealth App usability questionnaires used by Healthcare Providers and mHealth App usability questionnaires used by patients respectively, respectively. (See attachments)

The results of the respondents on the ease of use of the telemedicine application and their overall satisfaction as regards the acceptability to deliver healthcare services formed part of the manuscript paper titled “Digital Health Inclusion: A Pilot Study of Health Services Deployment Using Communications Satellite for the Underserved in Nigeria” and was submitted to International Journal of Telemedicine and Applications with the following metrics:

- ✓ *Acceptance Rate: 23%*
- ✓ *Submission to final decision: 116 days*
- ✓ *Acceptance to publication: 24 days*
- ✓ *CiteScore: 3.900*

- ✓ *Journal Citation Indicator: 0.670*

Lastly, our survey and first-hand experience during medical outreach in the field revealed the following:

i. Worm infestations such as tapeworms, roundworms and pinworms, were very prevalent at Gwazaye Community as revealed during our three-day medical outreach located in Kaduna State (Northern Nigeria) which was in close proximity to Aviation Medical Clinic, Kaduna International Airport. Over 300 children were registered and administered with Albendazole for deworming. The medication was available in tablets and suspension.

ii. Certain health trends and issues were noticed and established at IDP camps relating to sexually transmitted diseases (STDs) amongst inhabitants, poor environmental conditions and management in the camp including security challenges, as seen at the IDP Camp in the Central Part of Nigeria.

iii. Somatoform disorder was also discovered to be a common and prevalent disease among the elderly people of the Ikot Ekpene Udo community located at Akwa Ibom in Southern Nigeria including common eye diseases and vision problems.

iv. The oral interviews that were administered to healthcare providers and patients revealed the capability of the mHealth App and the entire project in reducing medical tourism by Nigerians abroad.

The health trends already formed part of the recommendations that will be forwarded to the relevant national health stakeholders.

4.3 Action Research

A robust network design was adopted for the application of communication satellite technologies to deliver broadband for telemedicine. This was implemented in line with the Nigerian National Broadband Policy of 2020-2025. The research was performed in the form of medical outreaches in two locations within Nigeria:

i. Deployment of a VSAT system at the Aviation Medical Clinic, Federal Airport Authority of Nigeria (FAAN), Kaduna.
ii. A remote underserved community in Kaduna State Nigeria with no primary healthcare facility and low internet connectivity.
iii. The New Kuchingoro Camp for IDPs Abuja, Nigeria.
iv. Cottage Hospital Medical Outreach at Ikot Ekpene Udo; Nsit Ubium Local Government Area of Akwa-Ibom State in Southern Part of Nigeria. We collaborated with additional Medical Personnel (both those in training and postgraduate students) from the University of Uyo Teaching Hospital within the vicinity of Akwa Ibom State, which exposed them to telemedicine experience with a potential for future collaborations.

The robust network employed for the outreaches consisted of the following primary elements:

4.3.1 One2One mobile Application for Accessing Healthcare Personnel:

Telemedicine poses a solution to the healthcare delivery challenges in Nigeria. It achieves this by bridging the gap between patients and medical personnel conveniently. One2One mobile application, which is already made available for free on Google playstore, is the tool adopted for bridging the distance, in this case. The One2One mobile application was specifically designed for delivering telemedicine services. The One2One application has two versions: a patient version and a version for the medical personnel called the One2One Healthcare Patient and One2One Healthcare Doctor applications, respectively.

The One2One Healthcare patient application as depicted in Figure 1 consists of the patient's information and has the ability to on-board the list of registered doctors and their specializations from the system's database. The application for medical personnel contains the patients' biodata and the list of other doctors with access to the application and their specializations. Doctors from various parts of the country and from different specializations are registered and accessible on the One2One application, thus, solving the problem of unavailability of skilled medical personnel.

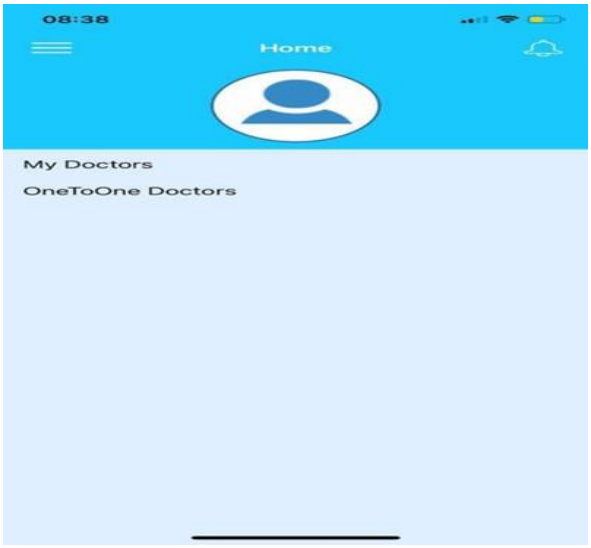

Figure 1. Illustration of the mobile application

Source: L.S. Lawal

The One2One mobile applications have a friendly graphical user interface (GUI) and are compatible with both Android and iOS devices, with the backend built on AWS cloud. The stack used on the backend permits video calls based on Web Real-time

Communications (WebRTC) peer-to-peer (p2p) open source technology, while the chat feature is based on Extensible Messaging and Presence (XMPP) Protocol. Consultation is available in the form of audio call, video call and chat. The chat feature has the capability to send and receive images, video files and text chat. The One2One healthcare doctor application permits the doctor to invite the patient(s) via SMS or social media. Prescription management is available on the One2One healthcare doctor's application where the doctor can add summaries and prescriptions to specific consultations. The patient application permits viewing of the prescriptions with the options of printing or sharing them.

The mobile application solution is secured end-to-end in accordance with the Health Insurance Portability and Accountability Act (HiPAA) of 1996 guidelines and works on IP Internet networks. The cloud backend has its own database and end-to-end security. The application solution is scalable, reliable, and can be deployed anywhere in the world.

4.3.2 Satellite Broadband

Due to the sparse nature of Internet connectivity in the communities visited, the mobile application relied on satellite broadband to provide reliable Internet connectivity. This connection was made possible via the Nigerian Communications Satellite (NIGCOMSAT-1R). NIGCOMSAT-1R is built on Dong Fang Hong-Four (DFH-4), a satellite bus that is similar to other high powered communications satellite bus such as Airbus E3000 Satellite Bus, Boeing 702 Satellite Bus etc., and was launched in December 2011. The communication satellite is a 9kW, quad-band spacecraft with a designed life span of 15 years. Since its launch, NIGCOMSAT-1R has been providing coverage in areas without terrestrial networks. Hence, its services became important in providing connectivity to unserved communities including the banking sector, military, aviation, broadcast sector and backup services to critical service providers to mitigate against the risk of unavailability of terrestrial networks as a result of flood, cut optic fibre, or damage and other natural disasters A Very Small Aperture Terminal (VSAT) was mounted in the communities and connected to the satellite on the Ku-band. The VSAT integrated an antenna, an orthogonal mode transducer (OMT), and a low noise block (LNB) to track, transmit and receive the signal from NIGCOMSAT-1R. The received signal was further transmitted to a satellite modem. From the modem, the connection was extended to a wireless router to ease the connection process for support staff. A signal strength of 17.45dB was attained from the setup. To further ensure optimum Internet connectivity, a dedicated bandwidth of 2Mbps uplink and downlink was allocated to the setup by NIGCOMSAT.

Figure 2 shows a brief view of the connection setup.

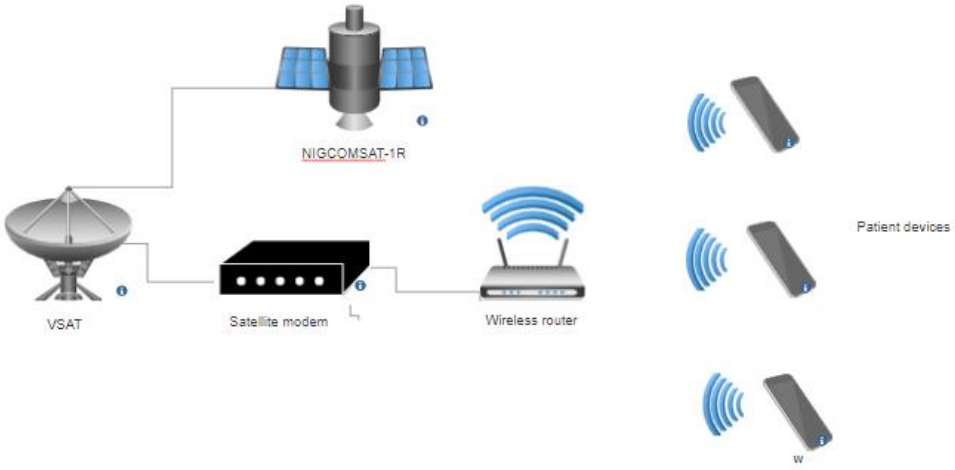

Figure 2. Connection from the satellite to the communities

Source: Satellite for Digital Health (S4DH) Research Project

The high-powered, quad-band (Ku, C, Ka, and L Band) geostationary satellite with designed life span of 15 years and an orbital home of 42.5 degrees east was designed to provide strong footprints across the sub-Saharan region of Africa, part of Europe, and Asia to meet the telecommunication and broadcasting needs of clients and service providers including Navigation Overlay Service (NOS) requirements similar to European Geostationary Navigation Overlay Services (EGNOS).

4.3.3 Support Staff

The mobile health application and satellite broadband successfully delivered satellite-based digital health services to the community. However, the majority of the residents were not fluent English speakers and did not possess basic digital skills. Hence, there was a language barrier and digital literacy gap. To address this gap, the services of volunteer support staff were co-opted into the outreach programme. The volunteer support staff had a good command of both English and Hausa, the most common language spoken among members of both communities. Hence, they assisted patients in the use of the mobile application. They also assisted in measuring body weight, temperature, and blood sugar levels of the patients.

4.3.4 The Process Flow

The modus operandi of the medical outreaches is as depicted in Figure 3. When patients arrived at the outreach site, they were welcomed by the support staff who also recorded their body temperature, body weight, blood pressure, and blood sugar level

on the mobile application. The patients then proceeded to join a queue and await their turn for consultation. The doctors communicated with the patients through the application, with the support staff serving as interpreters. For physical examinations, video calls also were employed to increase the effectiveness.

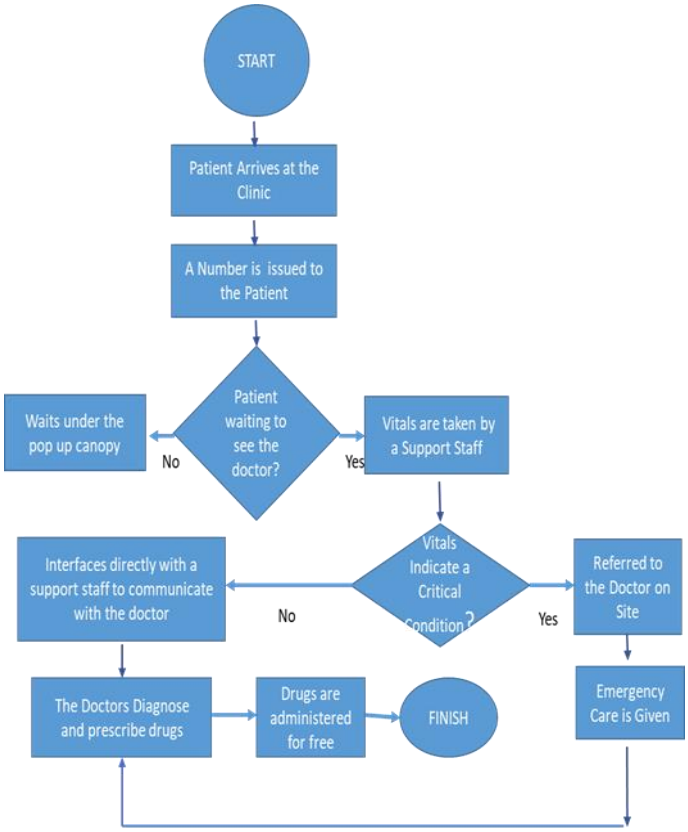

Figure 3. Process Flow

Source: Satellite for Digital Health (S4DH) Research Project

5. Results

The feasibility and general acceptance of digital health among members of underserved communities in Nigeria were evaluated in the course of the project. A total of 766 patients were attended to during the Connect2Recover (C2R) medical outreach programmes held from February 25 to February 27 and April 29 to May 1 2022. About 62% of the population of the patients were females while 38% were males. Their ages ranged from 0 to 80 with an average age of 23.

A survey was conducted using paper questionnaires to determine the usability of the One2One mobile application, the major communication tool over the course of the program. A total of 11 patients and health workers were recruited for the survey and the survey results were analyzed. Table 1 shows that most of the respondents found the application easy to use. 100 percent of the respondents were satisfied overall with the application and 81.8 percent strongly agreed that the application provided an acceptable way to deliver healthcare services.

Table 1. Survey Results of the Usability of the App

S/N	Statements	Strongly Agree (%)	Agree (%)	Not sure (%)	Disagree (%)	Strongly disagree (%)	Not Applicable (%)
1	The app was easy to use	90.91	9.09	0	0	0	0
2	It was easy for me to learn to use the app	72.73	27.27	0	0	0	0
3	The information in this app was well organized, so I could easily find the information I needed	81.82	18.18	0	0	0	0
4	The amount of time involved in using this app has been fitting for me	54.55	45.45	0	0	0	0
5	I would use this app again	81.82	18.18	0	0	0	0
6	Overall, I am satisfied with this app	72.73	27.27	0	0	0	0
7	This mHealth app provides an acceptable way to deliver healthcare services	81.82	18.18	0	0	0	0
8	The app adequately acknowledged and provided information to let me know the	72.73	18.18	0	0	0	9.09

	progress of my action.						
9	The app improved my access to delivering healthcare services	81.82	9.09	0	0	0	9.09
10	I felt confident that any information sent to my patients using the app would be received	72.73	9.09	0	0	0	18.18

Source :(Satellite for Digital Health (S4DH) Field Work).

Other results are:

i. Through oral interviews, healthcare providers and patients confirmed on the capability of the mHealth App and the entire project in reducing medical tourism by Nigerians abroad. The outcomes of the interviews were based on questionnaires in Appendices M3 and M4, and in particular, question 2g of the questionnaires.

ii. The robust satellite network designs were meant to deliver telemedicine services to rural and unserved areas as well as deploy mobile emergency response satellite kits in disaster locations and IDP camps to extend emergency healthcare services to the needy and the vulnerable group of citizens. The design also takes into consideration the earth station antenna diameter at the teleport, and uses link budget to deliver broadband services with the appropriate customer premise equipment (CPE) and bandwidth.

iii. There were also recommendations made to relevant authorities on VSAT-Based Telemedicine research findings, based on certain health trends in geopolitical regions of the country. In addition, there is a clear need for Government to collaborate with both private and public sectors to embark on ambitious health reform through sustainable tele-medicine centres and e-health facilities to guarantee the effectiveness of locally delivered healthcare system and reduce medical tourism.

6. Discussion

A major requirement for the deployment of digital health is the presence of fast and reliable internet access, which is not available in most underserved communities in Nigeria. To deal with this challenge, this project employed the direct use of satellite broadband to provide internet connection at the sites of the project, as opposed to the use of services provided by Internet Service Providers (ISPs). The satellite used was

the Nigerian Communication Satellite (NIGCOMSAT-1R), which transmitted and received signals from a satellite dish located on site. This means that the bandwidth used for the project was a dedicated one, resulting in the achievement of seamless internet connection throughout the course of the project. The internet connection provided via internet service providers is usually not without disruptions because of the use of shared bandwidth services for an optimized return on investment.

As stated earlier, major challenges facing the adoption of telemedicine in Nigeria are language barriers and the low literacy level of the population, especially in underserved communities. This issue was resolved by the introduction of support staff to serve as intermediaries between the doctors and the patients. The patients explained their symptoms to the support staff, and they relayed the messages to the doctors. The success of this approach is evident from the percentage of people (81.82 percent) who strongly agreed that they will use the application again if given the opportunity. The video call feature of the mobile application also assisted for the purpose of physical examination, especially in the case of visible skin conditions. The engagement of support staff is also a sustainable support system, because it bridges the gap between the digital approach to health care delivery and the low literacy level of the population.

To solve the problem of inadequate training of the frontline workers, we ensured that the support staff were literate, with a 100% of them having tertiary education. The doctors registered on the application were also carefully selected, and are all outstanding practitioners in their respective fields. More importantly, we ensured a strong interaction and information flow between the members of the team for the programme. Below is a brief illustration of the information flow in the team:

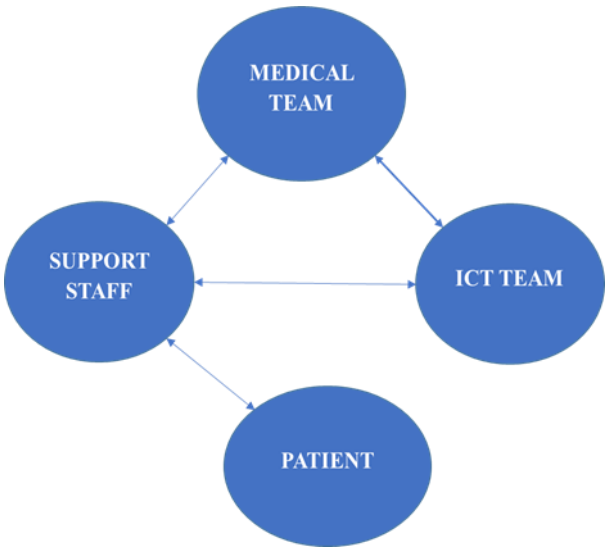

Figure 4. Illustration of the information flow in the team.

Source: (Satellite for Digital Health (S4DH) Research Project).

Prolonged clinic waiting time is also a major cause of dissatisfaction among healthcare consumers. To prevent any form of bias in the order in which patients were attended to, numbers were given to patients on arrival at the venue to ensure that patients were attended to on a first come first served basis. This also made crowd control easier. A waiting area was also provided, which consisted of chairs arranged under pop up canopies to address the issue of over-crowding. Because of the organized method of attending to patients, each patient spent an average of seven minutes from the time they started a consultation with a doctor, to the time they were able to collect their drugs and leave the clinic.

The low physician-patient ratio across Nigeria has been identified as a cause of poor services in the healthcare sector. The presence of multiple Doctors on the application at a time balanced the workload of the health practitioners by reducing the physician to patient ratio and making it possible for 5 or more patients to be attended to concurrently.

The end-user motivation was high. This can be seen by the fact that not less than 110 patients participated and were attended to on each day of the project. This may also be attributed to the availability of free medicines at the clinic as prescribed by the health practitioners.

Overall, the optimized one2one telemedicine app effectively delivered via NIGCOMSAT-1R Communications Satellite can be used in tele-medicine centres and e-health facilities to guarantee an effective locally delivered health system that will reduce medical tourism essentially based on the positive response of oral interviews received from healthcare providers and patients during the six month course of the project via the questionnaires administered (Samples of questionnaires administered are as provided in Appendix M1, M2, M3, M4, M5 and M6).

7. Recommendation

We would like to provide the following policy recommendations on National ICT strategy, and to drive digital health inclusion in Nigeria and Africa in general.

It should be noted that the objectives of our recommendations are not meant to introduce new legislation, or changes to existing laws. Rather they are defined strategies for government and stakeholders in health institutions that are meant to improve and strengthen existing policies or services and additionally to draw attention to a local issue(s) based on research outcomes and outputs:

- mHealth Software applications that is made available freely on Google playstore can be effectively delivered via communications satellite to tele-medicine centres and e-health facilities to guarantee effective locally delivered

healthcare system and reduce medical tourism particularly for citizens living in rural and unserved locations.

- Telemedicine can only work with sufficient broadband bandwidth. Communications satellite networks can provide the required connection quality with great consideration to teleport antenna, Customer Premise Equipment, VSAT sizing and dedicated bandwidth for a Time Division Multiple Access (TDMA) network. Thus, they are a viable option to provide services in rural areas; underserved and unserved locations in developing countries. This project determines the potential for deploying such a solution in Nigeria to address digital health inclusion and digital health insurance inclusion of vulnerable citizens in IDP camps.

- Specifically, the project also investigates the resiliency of communication satellite technologies to deliver broadband for telemedicine in rural areas of Nigeria using an app designed as a distributed peer-2-peer network referred to as one2one app with two variants available on play store (One2one healthcare doctor for specialists and One2one healthcare patient for patients). It leverages on specialists around the world to enhance and improve sustainable healthcare service delivery in rural and urban areas. The aim is to validate the case for delivering rural and community healthcare services sustainably with near real-time consultation (video, voice and chat messages).

- The research project also explored the creation of a mobile emergency response facility that can quickly be deployed to a disaster location to extend emergency healthcare service delivery and thus, makes a critical contribution to enhancing African nations' disaster response preparedness and effectiveness in utilizing communications satellite technology. An example is the use of satellite mobile kit to deliver telemedicine medical outreach at IDP camps. The same satellite solution can be utilized by National Emergency Management Agency (NEMA) Fire Services and Humanitarian services to not only deliver and extend healthcare services to the needy during disasters but also Internet services and e-learning suites for children that are out of school etc.

- A major contributor to poor health management among inhabitants particularly those in IDP camps is financial constraints. Many of them were well aware that they have certain medical conditions like hypertension, STDs, hemorrhoids, and diabetes, but they couldn’t manage them effectively because they can’t afford the required medical care, and thus, health insurance could be extended to these citizens, among other palliative measures. For instance, a National Health Insurance Scheme could work out a scheme to extend insurance policy to vulnerable citizens in IDP camps through digital health insurance inclusion measures.

- In collaboration with the Federal Ministry of Health and other relevant Health Agencies, a web portal can be accessed by each tele-medicine centre in different localities with information dissemination on epidemics, pandemics and other useful information. For example, content is published on HIV/AIDS prevention and control, for National Quality Management Programme on adult and pediatric care and treatment, prevention of mother-to-child transmission (PMTCT); counselling and testing and early warning indicators; malaria prevention and control information (use of insecticides, anti-mosquito nets, etc.); information on prevention, control and managing fire disasters, floods, etc.; and general community health programmes (how to create and maintain clean environments), as well as Ebola virus disease outbreak control. The portal provides content published in English and the major languages within the region of the country. This enables effective dissemination of health information in the community, saves lives, and reduces expenditure of foreign reserves on antiretroviral and malaria drugs.

- Need for the Federal Government to invest heavily on four key specialities of Medicine which accounts for 60% of Medical Tourism according to the 2016 Price Waterhouse Coopers Report which states that Nigerians spend over $1 Billion annually on Medical tourism. The four specialities are ***Oncology, Orthopedics, Nephrology and Cardiology*** as well as partnership and collaboration with hospitals and institutions with specialities in this field for availability of their medical expertise on the software application platform. This implies increasing the budgetary allocation to the health sector as well as investing largely in digital economy by making provision for digital economy in the national budget, which will in turn encourage private sector investment as well.

- Sensitization of the public on the importance and benefits of adopting digital health and investing in the digital economy may also contribute positively to the adoption of digital health.

- Management and maintenance policies should be made to ensure that the resources made available are well managed and as well maintained. These have the potential of reducing medical tourism that is costing the nation's economy heavily.

- Poor environmental management in IDP camps is another worrisome and major contributor to the diseases at the camp.

- Security challenges are also an issue in some of the camps due to their lack of access control to outsiders etc.

- For further information on our research project and activities, please visit www.s4dh.com.ng

8. Conclusion

This is beneficial research as it facilitates digital health inclusion for all via communications satellite in line with United Nations SDGs, particularly Goal 3 on “Good Health and Well-being”. The project trial was very useful and helped to provide an essential service to those in rural areas with limited digital skills. The mHealth software application effectively delivers tele-medicine consultations locally, which can help reduce medical tourism as confirmed by respondents of the questionnaires administered to healthcare providers and patients (particularly based on the oral responses to questions 2g of Appendix M3 and M4 by healthcare providers and patients).

In underserved communities across Nigeria, digital health presents a tool to close the gap between the inhabitants of such communities and medical personnel, who are usually based in urban locations, including the ability to conduct medical consultations with medical professionals anywhere in the world without embarking on physical travel outside the shores especially as it concerns follow-on consultations. However, to ensure its general adoption, digital health practice in Nigeria must take into account, the peculiar challenges faced in our environment, such as;

i. low Internet penetration.
ii. language barriers and
iii. the lack of end-user motivation.

This project produced an encouraging turnout of patients, and the large number of patients that were attended to during this project indicates that the adoption of digital health using health applications to deliver telemedicine via communication satellites can effectively deliver health care services particularly for citizens living in rural and unserved locations and reduce medical tourism. Moreover, those who previously visited countries abroad for major operations need not do so subsequently, for follow-on consultations, as telemedicine applications can suitably be used to reduce costs.

Despite the higher proportion of the survey respondents being satisfied with the mobile application, and the process flow of the outreach, efforts can be made to further automate the process. Future work can therefore involve the incorporation of a language translator in a mobile application for e-health deployment. This will enable patients to express themselves better and directly to the healthcare personnel, instead of through intermediaries.

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Good health and well-being is one of the 17 SDGs established by United Nations in 2015. The third goal in full is: To ensure healthy lives and promote well-being for all, at all ages. With the outcome from our research and fieldwork conducted so far, it

won't be an overstatement to say that communications satellites can play an invaluable role to contribute towards the achievement of Goal 3. This is because Africa remains the least wired continent in the world. In Nigeria alone, 31.6 million live in areas without telecommunications coverage (unserved) representing 15.12% of the population, who live in 114 clusters, according to Nigerian Communications Commission's (NCC) report and as contained in Nigerian National Broadband Plan 2020 – 2025 document.

Finally, four (4) papers were produced surpassing two (2) indicated in the expected result. These will be published in refereed conference proceedings (CP) and journals. As of 20th June, 2022, three have been submitted to upcoming conferences and Elsevier Journal. The title of the Four (Papers) and their status are as follows:

i. Digital Health Inclusion: A Pilot Study of Health Services Deployment Using Communications Satellite for the Underserved in Nigeria. *Submitted to International Journal of Telemedicine and Applications with the following metrics: (Acceptance Rate: 23%, Submission to final decision: 116 days, Acceptance to publication: 24 days, CiteScore: 3.900, Journal Citation Indicator: 0.670 (See Appendix G for further Details of Paper).*

ii. Overview of Satellite Communications and its Applications in Telemedicine for the underserved in Nigeria: A case study submitted to the 2nd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME). Notification of Acceptance was communicated on 16th August, 2022 and Conference Date is 16-18 November 2022 at Maldives. We registered our paper for virtual attendance and was delivered on 17th November, 2022 with certificate of participation issued. IEEE Copyright and Consent Form has been signed recently for publication in IEEE xplore (See Appendix H for further Details of Paper).

iii. A Review of Telemedicine and its Potential in Developing Countries submitted to the 8th International Conference on Mechatronics Engineering (ICOM'22). Notification of Acceptance was communicated on 30th June, 2022 and Registration for the Conference with payment has been made and Paper Presentation sessions on 9-10 August, 2022 at Kuala Lumpur (Virtual). The paper has since been delivered. We recently produced the paper in IET template format and signed IET Assignment copyright for publication in IET explore (*See Appendix I for further Details of Paper).*

iv. Internally Displaced Persons (IDPs) in Nigeria: An Overview of Health Situation *to be Submitted to a suitable Refereed Journal. (See Appendix J for further Details of Paper).*

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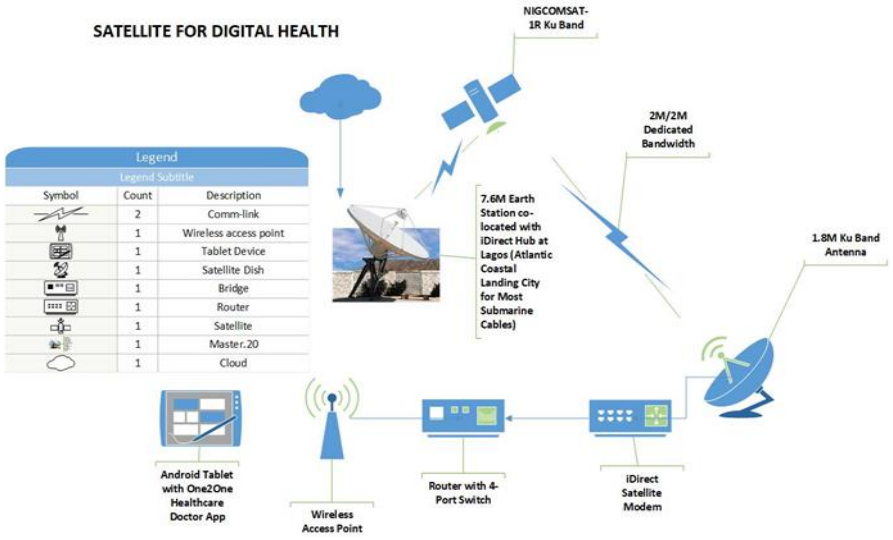
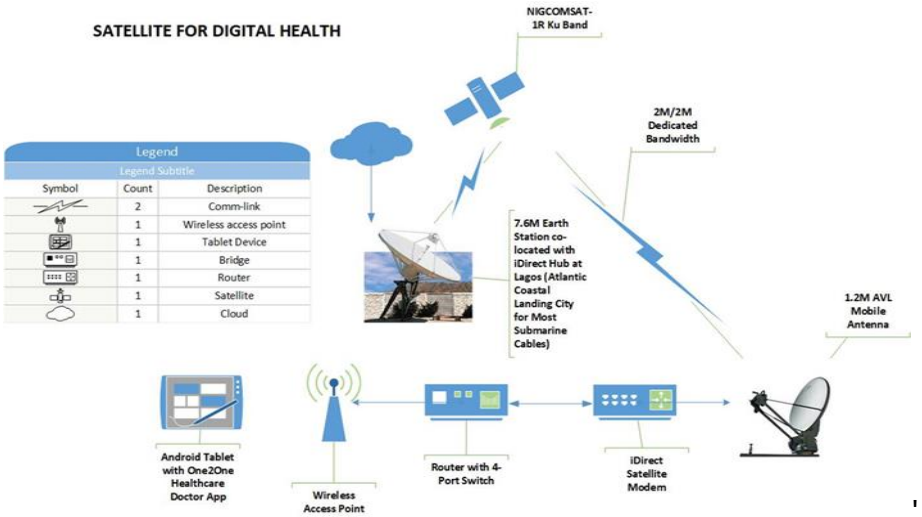
10. Appendices

Appendix A: Robust Network Design for the fixed site at Aviation Medical Clinic, FAAN, Kaduna



Appendix B: Robust Network Design for Mobile Emergency response satellite Kit deployment in disaster locations and Internally Displaced Persons (IDP) camps to extend emergency healthcare services to the needy



Appendix C: A Photograph of the Commissioned 1.8M Ku Band VSAT with dedicated 2M/2M Mbps Bandwidth.

Appendix D: A Photograph of the Resident Doctor's (Co-Investigator) Office with Indoor Units of The Satellite System and Accessories as well as a Standing Banner for Staff and Patients Awareness and Sensitization of Telemedicine Research Trial at the Aviation Medical Clinic, Kaduna.

Appendix E: Administration of 3-day medical outreach at host airport community and environs.

Appendix F: Mobile 1.2m Composite Ku-Band Reflector with Circular Hand Crank for Emergency/Manual Stow of Azimuth and Elevation Axes integrated with Ku-band 4W BUC and LNB undergoing series of tests before deployment in Internal Displaced Persons (IDP) camps.