Sustainable Development by Internet Backpack in the Democratic Republic of the Congo, Liberia and Costa Rica

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Abstract— Wireless grid research and innovation – what we now call cloud to edge or Internet of Things cyberphysical systems research - spearheaded by Syracuse University School of Information Studies (iSchool) with diverse partners and with support from the National Science Foundation's (NSF) Division of Engineering, and Computer and Information Science and Engineering (CISE) has led to the invention of an Internet Backpack which is capable of bringing connectivity anywhere, sustainably. The Internet Backpack is also a microgrid with a solar panel and battery included. This paper focuses on preliminary findings from ongoing Internet Backpack pilot deployments which were initiated in the Democratic Republic of the Congo in 2017, in Liberia in 2018 and in Costa Rica in 2019. We find that by design, the Internet Backpack's cloud to edge cyberphysical platform is capable of flexible and affordable connectivity across more than 11 physical and software-defined/cyberphysical networks, for over 90% of the planet. Further, we find that Internet Backpacks as a service can significantly contribute to accelerating the availability of affordable Internet access for the 3.5 Billion people presently excluded from full participation in realizing their individual human development due to, among other things, lack of Internet access. The paper concludes that Internet Backpacks and other Community Network platforms will likely become more readily available for education, disaster preparedness and other humanitarian uses because of their paradigm-shifting potential for connectivity cost reductions and service enhancements for many people and regions around the world presently largely excluded from sustainable development.

Keywords—Internet Backpack, Digital Inclusion, Connectivity, Humanitarian Technology, Sustainable Development

I. Introduction

The world celebrated that the Internet had reached over half of the global population by December 2018. However, neither 5G nor similar strategies can work to connect the predominantly low-income and/or remote communities excluded from the Internet today. The technologies and policies which brought connectivity to over half of the world's population are inadequate for digital inclusion of the next 3.5 Billion. Fortunately, there is evidence that a new approach to Community Networks may facilitate access for those who are excluded. For Internet Backpack users in the Democratic Republic of the Congo (DRC), Liberia and Costa Rica, 'Off the Grid Communication' is now a misnomer, since one need never be off the grid if the Internet Backpack's edgeware platform and its cellular mesh (and satellite) cloud to edge dynamic community network- creation capabilities are utilized.

This paper shares our preliminary findings and interprets their implications for sustainable deployment of the Internet Backpack. Our findings are broadly derived from pilot studies of community and user responses to the Internet Backpack in the DRC, Liberia and Costa Rica. Currently, twenty pilot studies are in various stages of implementation in eight countries, on four continents. We also summarize how key findings from the wireless grid research and innovation led by Syracuse University with diverse partners and with support from the NSF's Division of Engineering and CISE beginning in 2002, led to the invention of the Internet Backpack, which is capable of bringing connectivity anywhere, as it is also a microgrid with a solar panel and battery included. The paper focuses especially on early findings from the Internet Backpack pilot projects initiated in the Democratic Republic of the Congo in 2017, Liberia in 2018 and Costa Rica early in 2019.

Internet penetration in the Democratic Republic of the Congo is 6.2%, for a population of 81.3 million [1]. The high costs of services and the lack of infrastructure block most people from accessing the Internet [2], [3]). High Internet costs in the DRC are due to the high cost of satellite bandwidth use, which raises operating costs for Internet providers. Low Internet penetration in the DRC has impeded national development. The lack of infrastructure and inadequate material resources in the DRC is against the backdrop of decades of civil and regional armed conflict. In this paper, first, we summarize the methods and positive results of early

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technical and emergency preparedness evaluation by the Goma Volcano Observatory (OVG), DRC, where an Internet Backpack has been in continuous use since 2017. The backpack's ability to function at the top of a dangerous active volcano (Mt. Nyiragongo) when no other technology worked was demonstrated in 2017 tests. We present findings from the deployment of the Internet Backpack on Mt. Nyiragongo. The mountain is continuously monitored by the Goma Volcano Observatory and was selected as the first site for trial deployment. The backpack in Goma is also used for emergency preparedness training. The backpack was successfully upgraded in 2019 for CO2 monitoring with IoT sensors utilizing the IEEE LoRaWAN standard. Second, the paper illustrates how local schools in Liberia, another war-torn and resource poor setting, have demonstrated the utility and efficacy of the Internet Backpack for use for STEM education by primary school age children. Third, the paper examines policy implications from public-private-philanthropic partnerships in Costa Rica, an upper middle-income and politically stable country, to help to accelerate Internet adoption in remote and indigenous communities and increase the sustainability of community networks with the Internet Backpack's 'beyond the edge' platform. The paper concludes with lessons from the IEEE's and Internet Society's wide experience in developing humanitarian technology applications and community networks worldwide.

Additionally, this paper provides the basis for a proposed GHTC 2019 panel discussion with live demonstrations. The panel will discuss ways in which community connectivity for the next 3.5 Billion may be significantly different from either 5G proponents' promises, or the current costly network infrastructure architecture of leading service providers. Community networks are defined as networks structured to be open and unrestricted, which rely on the active participation of local communities in the design, development, deployment, and management of shared infrastructure as a common resource [4], [5]. Community networks and policies supporting Unlicensed Frequency Networks are emerging in places where traditional service providers cannot profitably deploy [6]. They are managed democratically by groups of individuals and entities such as NGOs, local businesses, and/or public administrators [7], [8]. The Internet Backpack is both a solar-powered microgrid as well as a new "off-grid" community network platform for up to 50 people, and a potentially much larger number of IoT sensors, which is always on grid. Discussions for this panel include: What role can Internet Backpacks play in extending the Internet to the next 3.5 Billion? Or, are such innovations and community networks more generally destined to be a temporary respite – before 5G reaches most of the world?

Panelists will draw on their experiences contributing to community network research and development and Internet Backpack projects in Africa and Central America to share preliminary findings and contribute to discussions of alternative future scenarios and technology enablers for connecting the next 3.5 Billion.

II. BACKGROUND

Design and development of the Internet Backpack grew from exploratory research begun in 2002, with support of first and second NSF Partnerships for Innovation grant awards (2002 and 2009). Demonstrations of potential commercial significance of research results (2014) were followed by pilot deployments (2017 to 2019). First (pre-)commercial beta sales occurred in 2017. Wide availability has been challenging, as many technical and socio-technical barriers needed to be addressed over the years. Doctoral theses such as [9], [10], [11], [12] [13], [14] and prior studies such as [15], [16], [17], [18], [19], [20], [21] have contributed to the incremental growth of knowledge and research insight needed for the Internet Backpack to eventually become reality. These studies have contributed to eventually enabling the Internet Backpack's complex dynamic cyberphysical system to securely and reliably operate anywhere in the world. In May 2018, prototype beta versions of the Internet Backpack were demonstrated to US Congressional staff and Senators under the auspices of the IEEE, as an example of the positive, long-range benefits of federal investment in science and technology research. The IEEE also supported introductory demonstrations of the Internet Backpack at the UN IGF in Paris, Fall 2018. We propose to collaborate with IEEE members in discussion at GHTC 2019, and in demonstrations and a panel discussion with colleagues participating from academia, industry, the technical community and civil society.

III. INTERNET BACKPACK DESIGN AND FUNCTIONALITY

The Internet Backpack is a remote connectivity solution. It includes a range of IoT devices, which, combined with edge software, (we term this software *edgeware*), mobile platforms, Wi-Fi, satellite, and battery power, can connect team members and their devices in stressed environments and remote locations. The edgeware platform has the potential to exponentially multiply the positive impact of community networking in remote areas. With connectivity, the use of IoT solutions can allow local communities to utilize the dividends of this technology with limited investment, through activities such as more effective approaches to disaster management and more inclusive educational practices. The self-powered and self-contained Internet Backpacks are equipped with a variety of technology tools, including a high-powered lithium ion battery, a 50-watt foldable solar panel that allows the battery to recharge when standard AC recharging is unavailable, off-grid communication devices and power adapters, AC adapters, USB cables, international converters, at least two smart devices such as a cell phone or tablet, and a small satellite connectivity device. To integrate these components and ensure that a variety of key applications are always connected, the backpack utilizes an all-in-one edge routing solution that supports cellular based broadband, satellite, Wi-Fi and GPS. Importantly, the global deployment of the Internet Backpacks also requires a robust cloud-based network management system that can allow its IT or customers' in-house teams to monitor and troubleshoot connectivity challenges remotely.

Figure 1. Internet Backpack for Edge Connectivity
(Source: Imcon International Inc. Used with permission)

Figure 2 below illustrates a virtual international session among various project partners held on May 12, 2017, to discuss and introduce the Internet Backpack's capabilities to colleagues in the Democratic Republic of the Congo. The first deployed Internet Backpack arrived in the DRC approximately one month later, for use by the Goma Volcano Observatory and local schools for education and emergency preparedness activities.

Figure 2. Introducing the Internet Backpack to the Democratic Republic of the Congo, May 2017
(Source: Syracuse University School of Information Studies, WiTec)

IV. DIGITAL INCLUSION WITH THE INTERNET BACKPACK

A. Monitoring Mt. Nyiragongo with the Internet Backpack

Mt. Nyiragongo is a stratovolcano, located in the Virunga volcanic province, in North Kivu, the DRC [22]. In January 2002, in a major eruption, Mt. Nyiragongo produced several lava streams, one of which reached the city of Goma, covering 13% of the city [23]. Approximately 100 lives were lost. Out of an estimated population of 450,000 people living in the area at the time, approximately 300,000 to 400,000 people were displaced. An estimated 300,000 people fled to neighboring Rwanda, and approximately 100,000 moved to other locations within the DRC. The UN Office for the Coordination of Humanitarian Affairs (OCHA) developed a Regional Contingency Plan for the Great Lakes Region to assess the immediate response to the Mt. Nyiragongo volcano emergency. The plan noted areas that could be improved, including coordination of decision-making mechanisms, dissemination of public information, information sharing and delegation of tasks and improved resource mobilization processes [24]. The destruction of businesses and homes in the wake of the 2002 eruption disrupted economic activity for Goma residents, many of whom were already living in highly vulnerable conditions prior to the disaster [23]. Many residents lost their livelihoods in the volcanic eruption, and in the aftermath, the unemployment rate was estimated at 95% [23]. The 2002 eruption was preceded by the 1977 eruption, which similarly caused deaths, displacement and destruction to the surrounding Goma region. These eruptions have had significant economic and humanitarian impact [25].

Scientists have predicted that additional eruptions are likely in the future. In April 2019, an earthquake of 4.3 magnitude was felt in the Bukavu-Kavumu region of the DRC [22]. The Goma Volcanic Observatory, with support from the United Nations, monitors Mt. Nyiragongo 24/7 and 365 days a year with seismic data produced and sent every four minutes, and temperature data produced every ten minutes. OVG's Seismology department monitors seismology swarm, magmatic seismicity and tectonic seismicity, which can trigger volcanic eruptions. Its Geochemistry department monitors SO_2 volume released by Mt. Nyiragongo. Under normal conditions, this volume is between 1000 and 12000 tons a day. CO_2 levels in fractures are also monitored. OVG's Deformation department measures temperatures in the fractures and opening up of fractures. Further, OVG's Remote Sensing department monitors thermal radiation and volumes of gas released [22]. The Internet Backpack deployment pilot program and the preliminary results show potential to work with the OVG and other local and international partners to improve the Mt. Nyiragongo early warning system and hence save lives in emergency situations. The principal objectives of the Internet Backpack pilot study [26] to Mt. Nyiragongo were to:

- observe how the satellite connection would work on the mountain, given the radio interference caused by its geochemistry
- determine how data could be transmitted from Mt. Nyiragongo to the OVG office in Goma
- Increase knowledge of the efficacy of the technology
- Make recommendations to partners to assist them in sending/receiving data
- Impact life and livelihoods of local communities in the vicinity of the volcano by increasing access to Internet technologies

The expedition to Mt. Nyiragongo commenced on August 22th, 2017 from the OVG Office. The first stop was at the Congolese Institute for Nature Conservation office in the town of Kibati, at the base of Mt. Nyiragongo. The satellite signal, network operators (Vodacom and Airtel) signals, and the coordinates of the zone were recorded at Kibati. The test of Internet by satellite was performed at the top of the mountain.

Figure 3. Connectivity Options with the DRC Internet Backpack beta, June 2017

Network	Frequency	Type
goTenna	151-154 MHz	MURS Multi-Use Radio Service Mesh
3G	850/900/2100 MHz	Mobile
4G	700MHz, 1700-2100 MHz, 1900 MHz, 2500-2700 MHz	Mobile
The Things Network	923.3 - 927.5 MHz Downlink 902.3 - 914.9 MHz Uplink	LoRaWAN Mesh
Thuraya Satellite Network	1.525 - 1.559 GHz Downlink 1.625 – 1.6605 GHz Uplink 2.4 GHz, 5 Ghz	Satellite Internet, data, voice Wi-Fi
GPS	1.57542 GHZ, 1.2276 GHz	Satellite Global Location
Bluetooth	2.4-2.4835 GHz	ISM (Industrial Scientific Medical) short range radio frequency
BluetoothLE	2.4-2.4835 GHz	ISM (Industrial Scientific Medical) short range radio frequency Mesh
Wi-Fi	2.4 GHz, 5 Ghz	ISM Mesh
Wi-Fi	2.4 GHz, 5 Ghz	ISM Central Server
Gridstream	Any	Over the Top/Software-Defined Overlay Network
GridstreamX	Any	Open edgeware communication messaging
Internet	Any	IP

(Source :Lee McKnight & WiTec, Syracuse University School of Information Studies)

Results of tests of the Internet Backpack on Mt. Nyiragongo

Approximately 13 units (SIM card airtime data units) were used at the top of Mt. Nyiragongo, which was comparatively low and less than what was expected. The peak of Mt. Nyiragongo is cold (+5 Celsius degrees to -5 Celsius degrees) and windy. It rained in the evenings, which allowed the August 2017 expedition to determine how the Internet Backpack would work in rain. The Thuraya satellite hotspot device was safeguarded in a plastic bag. When it rained heavily and for a long period of time, the signal was lost (0 to 3 signal bars). When it stopped raining, the expedition could transmit messages using GridStreamX, an edgeware application previously studied in an earlier version [12].

Figure 4. Software & Connectivity Tests (w Thuraya Satellite HotSpot) Mt. Nyiragongo Summit, 2017

(Source, Eliel, WiTec, 2017)

Application	Expected	Realized
WhatsApp	Send/Receive messages Send/Receive voice Send/Receive video	Unable to perform these tasks Attemptin g to connect
Skype	Send/Receive text messages Send/Receive voice call Send/Receive video call	Unable to perform these tasks Attemptin g to connect
Ping	Ping servers	Test was okay, could ping 8.8.8.8 at 2400 MS
Browsing Web	Could browse using any browser	No: only Opera Mini could open e.g., google.com and other websites. On the [illegible]

Wind did not interfere much with the connection on Thuraya, but it did interfere significantly with the connection with mobile operators such as Vodacom and Airtel. At certain times, including late at night, the signal from these operators was lost [26].

This test did not determine whether the Thuraya not allowing OPEN Socket on its network prevented the Internet Backpack from working with Skype and WhatsApp. The successful test of the GridStreamX edgeware application prototype which used HTTP protocol, opens at Socket and closes it at the end. The GridStreamX client-server dialog was developed using AJAX. Opera Mini compresses website data for low connection networks. It removes native JavaScript, redesigns CSS and compresses images. Also, GETHC was configured in Thuraya to disable image downloading. Further tests of Skype and WhatsApp were not performed at the summit of Mt. Nyiragongo so as not to use up the remaining airtime in the Thuraya. At certain times when just loading (WhatsApp or Skype), loading was canceled to not use up airtime. It was clear that with the Ping delay, many widely used Internet applications would not run properly without edgeware to reduce the data load required at the edge; in this case, on top of the volcano. Further application of the OVG Internet Backpack for community education, emergency response training, and IoT sensor (CO_2) monitoring in the Democratic Republic of the Congo has been successfully undertaken but is not reported on in detail here.

B. Deployment of the Internet Backpack at pilot schools in Liberia

The cyberphysical system's demonstrated efficacy in the DRC led to its next deployment in Liberia, beginning in 2018. The Internet Backpack is now used by the Ministry of Education and schools in rural and urban settings, including a school near the Nobel Peace Prize winner and former President Ellen Johnson Sirleaf's farm. The former Liberian President is especially supportive of use of the Internet Backpack for rural and remote education to help the underserved children of Liberia, and the hundreds of millions of children around the world who are excluded technologically from full participation in education opportunities. A ten-school pilot began in 2019 in Liberia, with support from the Ministry of Education, civil society, foundations and business community leaders. An expansion is sought by a public-private-philanthropic partnership, to bring the Internet Backpack to all schools in the country as part of a national pilot project to help the country advance from 8% Internet access (of a population of more than four million) to 40% by 2021; or due to delays in launching the effort, by 2022. Importantly, the backpack's cyberphysical cloud to edge platforms themselves are not sufficient; deployment of a nationwide unlicensed frequencies educational network is also planned to serve as a low-cost national backbone for sustainable development of education, emergency and health services in Liberia. Such deployment would also be particularly helpful in facilitating the general utility and operation of community networks.

Project partners in Liberia include One Planet Education Network (OPEN), the Ministry of Education, Ministry of Health, Ministry of State, Ministry of Posts and Telecommunications, Liberian Telecommunications Authority, Imcon Liberia Foundation, Muslim Congress High School and Bethesda Christian Mission School. OPEN provides the curriculum for the 40-2021 Liberian Initiative. The Internet Backpack technology is integrated into the curriculum. The curriculum includes international STEM + (STEM Plus Humanities and Arts) transdisciplinary program series, community service focused project-based learning programs, international distance learning program management, real world-based educational games, and VR/AR educational content. In cooperation with Syracuse University, OPEN will also provide 'train the trainer' teacher training and technologists with professional development and technological support. Primary services provided with the STEM + curricula include an Internet Sensor (IoT) STEM class and field lab application hardware, software, networks, and data analytics, and related GIS digital mapping applications. At the pilot schools, the Internet Backpack connectivity system has performed as intended, even during torrential rainstorms and constant power outages (with frequent connectivity interruptions for systems that rely on power grids, as opposed to the Internet Backpack's self-reliance for energy). It has thereby allowed the schools to continue teaching and learning without interruption. Students and teachers at both of the initial pilot schools have participated in live international education sessions with their peers in other countries. They have also participated in sessions with scientists from Hawaii and California (US) and Kenya, experts in sustainable agriculture and forestry, and with volcanologists working on Community Emergency Services education programs from Hawaii Volcanoes National Park and the Goma Volcano Observatory. Liberian students have also received virtual lessons from an Internet Sensor technology expert in Amsterdam, Holland [27]. These educational activities show the Internet Backpack's capacity to function in stressed environments during utility power interruptions, and also how its long-lasting battery pack can continually be recharged for ongoing Internet and localized small-scale power service via its on-board solar panels, in this specific case, for rural education. In 2018, a Memorandum of Understanding was signed by the Government of Liberia, Syracuse University, and Imcon International Inc., committing all parties to continue collaboration and work with foundations and firms to bring connectivity and new educational opportunities to all schools in the country. Additional funding support is being sought for this ambitious initiative.

C. Deployment of the Internet Backpack in Isla Caballo, Costa Rica

Deployment of the Internet Backpack in Central America began in 2019 in Costa Rica, with support from a local public-private-philanthropic (multi-stakeholder) partnership of the government, a coalition of foundations, and the business community. Partners include Viva Idea, MarViva Foundation, the Zamora Terán Foundation and the Democracy Lab Foundation. The Viva Idea Foundation provided the funds to the MarViva Foundation to obtain the first Internet Backpack deployed in Latin America. Isla Caballo, a remote island location without running water or electricity, was selected as part of a pilot project to support coastal communities. The Zamora Terán Foundation has donated computers and will train teachers and the local community as to how to use the computers. The Democracy Lab Foundation, a non-profit foundation dedicated to helping citizens achieve civic engagement with their governments in Central America, coordinates the project [28]. The unique capabilities of the Internet Backpack for enhancing access to digital inclusion opportunities with national broadband education networks and Internet Backpacks for 'the real last mile' for rural schools and indigenous communities is the focus in Costa Rica, where up to 800 Internet Backpacks are envisaged to be deployed for remote and indigenous community education. Costa Rica is pioneering use of the Internet Backpack for connectivity for rural areas, schools, and indigenous communities, which traditional networks could not affordably reach. The Internet Backpack provides an immediate connectivity solution that allows users to be able to communicate from almost any location and easily build their community networks. The self-contained Internet Backpacks offer the mobility and flexibility to virtually connect any small group of users and can be a solution for connectivity for students, teachers, farmers, first responders, public administrators and many others in remote areas across the globe. This model for digital inclusion, implemented in Isla Caballo, leverages the capabilities of the Internet Backpacks. Figure 5 illustrates.

Figure 5. Internet Backpack Initial Deployment Results, Isla Caballo, Costa Rica, March 2019

Isla Caballo, Costa Rica	**Isla Caballo, Costa Rica *with Internet Backpack for 4 minutes***
250 residents	250 residents
No running water	No running water
No electricity	**Microgrid**
No Wi-Fi	**Wi-Fi**
No Internet	**Internet**

(Source: Alvaro Salas-Castro and Phillip McKnight, Democracy Lab, and Lee W. McKnight, Syracuse University)

V. Conclusion

Wide availability of the Internet Backpack is projected for 2020. Fair Trade Data (blockchained capabilities) can be expected to be pre-loaded on the Internet Backpack from its (mass) market introduction, along with the IEEE IoT data networking standard, LoRa, cellular, satellite, Bluetooth and Wi-Fi access. The implications of the humanitarian technology innovation of the Internet Backpack for sustainable development are significant, with contributions to connectivity and communication; disaster mitigation, preparedness, response and recovery; and technology enhanced quality education delivery being evident from early results from deployments of Internet Backpacks, as discussed in this paper. The educational, emergency preparedness, and inclusive social and economic opportunities emerging from the new edge cyberphysical platform are evident from the first trials and pilot projects, on which this paper shares initial findings.

The sustainable by design Internet Backpack permits up to 50 users and 250 devices to share connectivity and device resources, anywhere, with a set-up time in the field of 4 minutes, as demonstrated on Isla Caballo, Costa Rica. It can be conceived of as a 'Pop Up Community Network.' Based on innovative edgeware services (cloud to edge low bandwidth utilities), graceful degradation across 11 networks, leveraging Bluetooth, Wi-Fi, LoRa, 3G/4G data, and satellite Internet access and sharing technologies, the Internet Backpack is capable of supporting the original design objective for edgeware to ensure 'worst case scenario survival as a service,' as well as affordable resource-sharing for education and remote indigenous community access in less extreme circumstances. Finally, we acknowledge prior support from National Science Foundation grants #0917973 and #0227879 which made these findings possible and note that the views expressed are those of the authors and may or may not be shared by any institutions with which they are affiliated.

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