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Cognitive Cloud to Edge Systems for Remote Real Time Monitoring: CO_2 Sensing at Mount Nyiragongo Volcano, Employing the Internet Backpack

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***Abstract*— Cloud technologies and edge (Internet of Things) devices and services have been widely utilized to improve safety and community resiliency. However, in regions with low Internet penetration or even in well-connected communities temporarily 'off-grid,' accessing and coordinating these tools can be a challenge. The Conflict Zone volcano monitoring application explored in this paper may be considered an extreme case. The authors argue that the successful approach assessed in this paper may apply not only to uncommon circumstances. This paper focuses on the use of the Internet Backpack technology as a core part of a cloud to edge communication and information systems for monitoring sensors for early detection of CO_2 levels in the city of Goma, in the Democratic Republic of the Congo. The authors describe testing, implementation and challenges in the mountainous terrain encountered and overcome with the Internet Backpack, in cooperation with the Goma Volcano Observatory (OVG).**

Keywords*— *Cloud Infrastructure, Edgeware, CO_2 Monitoring, Internet Backpack, The Democratic Republic of the Congo, Nyiragongo Volcano.

I. INTRODUCTION

The Democratic Republic of the Congo (DRC) is a vast country with thirty-five provinces and a population of over 86 million. It extends over 2,345,000 km² in Africa, with an almost non-existent infrastructure in some areas. Approximately 48% of the population possesses a mobile phone, a quarter of which can access wireless broadband (3G or 4G) networks [1]. Mobile telecoms companies such as Orange, Vodacom and Airtel are the main internet service providers (ISPs)[2]. Despite recognition that the Internet is of paramount importance for economic growth, social well-being and sustainable development, access costs are high for the Congolese, whose annual income (PPP) is estimated as under 1,000USD [3]. As such. approximately 6.2% of the DRC population has Internet access. In addition, basic connectivity is significantly hampered by the lack of power and communications infrastructure as well as civil unrest within the country. For example, nearly a dozen active groups in combat exist in the province of North Kivu alone. Combination of these challenges significantly impacts upon connectivity; inhibiting DRC's participation in the global information economy and constrains its future social and economic development. Given a less than ideal solution in this region, this paper discusses an agile connectivity solution, cloud to edge wireless approach. The authors focus on providing a solution for on-the-ground connectivity in the North Kivu province, specifically the city of Goma and its surrounding environs.

The city of Goma (see Fig. 1) is built on the northern shore of Lake Kivu and lies 13-18 km (8-11 miles) from a stratovolcano, Nyiragongo Volcano. This area, known as the East African Rift System (EARS) and is under continued threat of highly active volcanoes. Efforts by OVG have been successful in alerting residents of volcanic eruptions and lava flows, yet a more continuing threat still needs to be addressed. Goma and its environs are at risk by the insidious CO_2 saturated waters in Lake Kivu and unceasing CO_2 seepage from lowland volcanic vents. Gas saturated waters lay deep in the lake, and can rise swiftly to the surface, without prior warnings, releasing large amounts of CO_2 and methane. This ever-present silent threat of localized CO_2 toxicity has led to many deaths by asphyxiation in the past and remains a public health threat. Many studies have focused on studying Lake Kivu, but little is

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known about the continual emission of gases through the crater and vents in the lower regions. To date, no detailed studies about these manifestations of CO_2-rich gases emitted from vents are available and researchers still debate about origin [4].

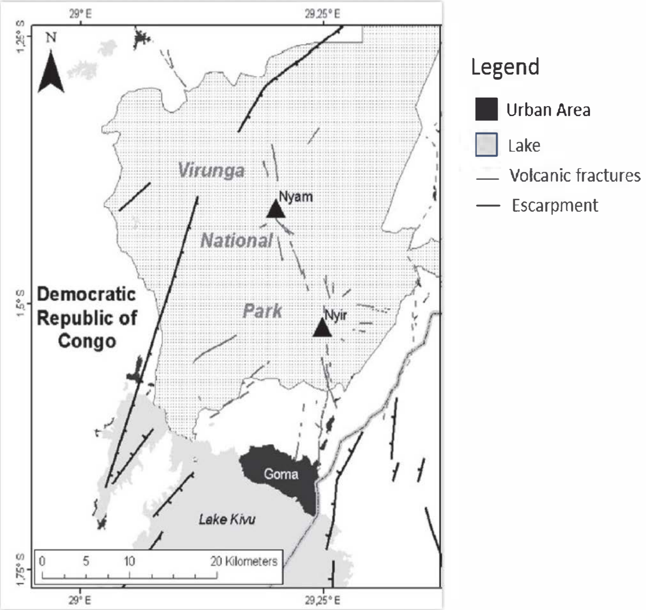

Fig 1: Map of Goma region with volcanic fractures and main escarpments [4]

II. CONCEPTUAL BACKGROUND

Engagement in early cognitive wireless network exploratory theoretical work recognized, timing, coordination of people and devices as very crucial in the cooperative delivery of data in emergency situations [5]. Research on leveraging wireless grids began in early 2000s. The capability to realize its applications is only now becoming a reality as bridging the gap among wireless network, middleware and grid (cloud) application layers becomes possible with edgeware and open radio access networks. Communication of network state information is stifled by layered protocol architecture, making individual elements unaware of the network conditions experienced by other elements, unless additional capabilities explicitly for achieving connectivity and trust in such circumstances are employed. The increasing complexity and heterogeneity of wireless networks led to exploration of open structures. This stage of research focused on specifications (See Fig. 2) developed with support from NSF PFI (NSF PFI#0917973) funded Wireless Grid Innovation Testbed (WiGiT) in 2009. The goal, to enable a more dynamic, cognitive approach of access-controlled interoperability across networks, applications, devices, content and services.

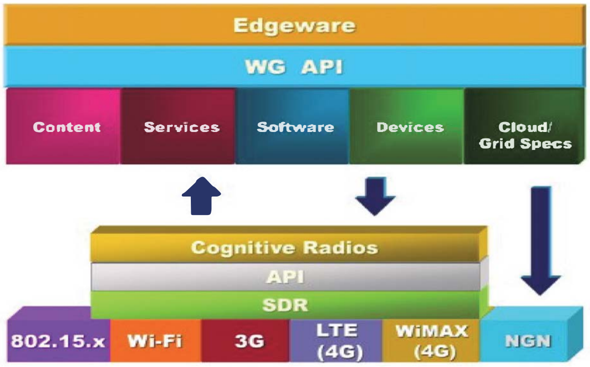

Fig 2: Open Specification Model

It is argued that functionality can be viewed as a front-end/user interface to heterogeneous resources, a mesh network used for sharing resources, as low-powered sensors networked together, or as other advanced broadband examples, including use of high-capability spectrum sharing technologies [6]. Characteristics include compatibility with many device types, such as mobile and nomadic devices, phones, tablets, laptops, and network computers. This preliminary work led to testing and evaluation of innovative emergency response solutions and advanced situational awareness systems [7].

Continued work had led to evolution of The Open Specifications Model. Currently at v0.5 which has been widely circulated, but not always understood given its complexity. The updated model suggests edgeware architecture to protect people, devices, networks, applications. data, content and services, and non-person entities, including edge networks and edge computing devices, and edge cloud services are being instrumented with sensors that are moving through a maturity model.

"Smartness" of objects instrumented with sensors is on a scale. Our belief is that the Internet of Things (IoT) will mature in a direction where data sets that are newer will be collected/streamed remotely over the Internet, the fidelity of the new data sets will increase and as sensors become more sensitive and scalable, and the smartness of the devices instrumented with sensors will increase over time to an Internet of Smart Things. In summary. this model is designed to create authenticity in Internet and IoT applications by closing the gap between the usefulness of IoT and its insecurity by making data and devices safer and less easily manipulated.

“Edgeware” highlighted in the model is the software that dynamically meshes devices, and media, permitting secure intelligent ad-hoc formation of networks of devices without a dedicated server for network management [8]. If proprietary, the term for an edge application of this type is a ‘gridlet,’ if open/non-proprietary, an edgeware application has been termed a ‘wiglet’ by the Syracuse University-centered research community which has pioneered this approach to seamless, trusted, on and off-grid communications and information-sharing. Following additional years of trials, we now (2019) focus on the first successful ongoing application of this technology in the Internet Backpack. [9], [10].

III. APPLICATION IN DRC

The remoteness of the region with no reliable infrastructure presented several challenges especially when considering the need for a base investment that remain relevant as technology progresses. This challenge was addressed in two parts: Power and Connectivity. Each component was envisioned to be independent, providing allowances for evolution of the technology and support structure over time. The following sections describes components employed to meet these criteria.

A. Power

The system needed to include off-grid solar power systems and small-scale power systems to power remote connectivity and sensor deployments. Hardware needed to be robust, at least 10-year lifetimes (battery charge cycles are regarded as the primary 'wear' item) to support this deployment and next generation uplink deployments to replace the proposed satellite link. Where terrestrial wireless backhauls or fiber networks may be reachable, the network would require further upgrading and reengineering, with much of the prior investment still contributing to the network. The Internet Backpack's combination of a foldable solar panel for energy generation, capable of recharging the battery with 15 hours of sunlight, and the careful calibration of the power budget (energy use) of included devices, means that the Internet Backpack may be considered a mini-, micro-, or nano-grid (no standard terminology available at present) as well as connectivity platform, as described below.

B. Connectivity

The aim was to provide Internet connectivity with a 100 megabit per second satellite uplink. However, this is not possible because of the absence of low Earth orbit (LEO) satellite in the region (orbit between 400 and 1,000 miles above the earth's surface). Sub Saharan Africa have geostationary satellites such as Thuraya (can handle 13,750 simultaneous voice calls) or Immarsat for mobile satellite devices. This is a constrained link for many modern applications but was regarded as enough for 30 concurrent users. Site connections was point-to-point wireless links at 500 megabits per second each. At each site, two to five Wi-Fi access points was deployed to provide connectivity for local devices.

The site hosted a LoRaWAN gateway (low-power wide-area network technology) to provide low bandwidth, long range connectivity for IoT and sensor applications to support data collection in surrounding areas.

Give the expense needed to procure and operate satellite equipment this represented approximately one-third of the total expense. In addition, satellite links offered limited bandwidth and suffered from high latency, limiting use of certain applications (e.g. voice or video calling, for example Skype). The satellite uplink acted as a modular component of the installation and was considered for replacement as soon as a more reasonable and performant option is available. Possible solutions could be terrestrial wireless, fiber optics, or LEO satellite which could address latency and constrained bandwidth but require local infrastructure build out.

IV. INTERNET BACKPACK DESIGN AND FUNCTION

To meet the power and connectivity challenges describe above, in this section we briefly describe the proposed portable solution, the Internet Backpack. The total weight is under 10 kilograms (22 pound), therefore easily carried for off the grid use. The design of the Internet Backpack leverages on edgeware and was developed to be Geo Mobile Packet Radio Service (GmPRS) capable. It is able to run with other networks such as LoRaWAN, Universal Mobile Telecommunications Service (UMTS a third-generation (3G) broadband, Long Term Evolution (LTE) 4G wireless communication, Bluetooth Off-grid mesh, and others, with the ability to adapt to network conditions [8]. It is a technology supportive of decentralized connectivity, and sustainable microgrid. Its self-powering is possible by being equipped with a high-powered lithium ion battery, a 50-watt foldable solar panel allowing 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. The system uses a combined edge routing solution (edgeware gridlet) that supports cellular based broadband, satellite, Wi-Fi and GPS. Its global deployment uses cloud-based network management system that can allow its IT or customers' in-house teams to monitor and troubleshoot connectivity challenges remotely.

While both 5G and new satellite systems have tremendous potential impact, they are not enough to sustain rural, remote and other vulnerable communities. Its immediate connectivity by cloud to edge design provides 11 to 20 networks and edgeware for connectivity. The connectivity options for the Internet Backpack used in the DRC are shown in Table 1.

TABLE 1: Connectivity Options with the Internet Backpack [10]

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, ISM Central Server
Gridstream	Any	Over the Top/Software-Defined Overlay Network
GridstreamX	Any	Open edgeware communication messaging
Internet	Any	IP

V. TESTING FEASIBILITY OF INTERNET BACKPACK

The Internet Backpack pilot program began in August 2017.

The objectives were to

1. Observe how satellite connection worked on the mountain, given radio interference caused by the volcano geochemistry
2. Understand data tranmission challenges from Mt. Nyiragongo to the observatory in Goma
3. Explore overall efficacy of the technology.
4. Make recommendations to partners who assist in sending/receiving data

Successful testing (see Table 2) of the GridStreamX edgeware client-server application prototype uses HTTP protocol, opens at socket and closes at the end [11]. Accessing Opera Mini can be attributed to its compression of website data for low connection networks. The Access Point Name (APN) GETHC was configured in Thuraya to disable images from downloading. As illustrated in Table 2, from the Ping delay, it was apparent that many widely used Internet applications would not run properly without edgeware to reduce the data load required at the edge; in this case, at the top (3,470 meters or 11,385 feet) of the volcano.

TABLE 2 Connectivity Tests

Application	Expected	Performance
WhatsApp / Skype	Send/Receive messages Send/Receive voice Send/Receive video	Unable to perform these tasks
Ping	Ping servers	Test could ping 8.8.8.8 at 2400 MS
Browsing Web	Could browse using any browser	Only Opera Mini could open e.g., google.com and other websites.
		On the laptop, could not connect to the Internet
GridStreamX (Edgeware)	Send/Receive text messages	Worked

A. Pilot Implementation to Measure CO_2

Given awareness of connectivity, next steps focused on applying the Internet Backpack as a communication means for monitoring sensor data. One of the goals behind monitoring activities is dependent on researchers understanding correlation of SO_2 gases at the mountain top and its impact on CO_2 production at fissures located in the city. An objective being, with adequate data OVG will be able to predict when CO_2 levels could rise based on SO_2 concentrations produced at the volcano crater. As of writing this paper, there is no direct relationship between SO_2 released by the volcano and CO_2 concentration in fissures located in the lowlands. In addition, with enough sensor data OVG can predict from which fissures lava will flow out in case of eruption as well as mapping areas of high concentration so that the population could be advise on avoiding these areas for farming and dwelling.

Relaying the data from sensors located around the volcano will involve the use of Things UNO (based on Arduino Leonardo) which has the LoRaWAN incorporated. The sensor system will transmit data to a LoRaWAN gateway found in the Internet Backpack. The Things Network cloud platform will make it possible to create a software gateway that connects to a definitive server (Microsoft Azure) using REST API to store data. Live streaming with the server will only be done when in the field with the Internet Backpack.

Continued exploration will address CO_2 sensors at the base of the volcano, the first phase of the sensor system deployment. These sensors were installed at an OVG station located in Bulengo an area where camps for internally displaced people are located. Researchers at OVG were cautious, regarding this location because of threat of robbery or malicious destruction. In addition, the geographic relief of the area proved problematic as sensors were not equipped with antennas and the signal could not be relayed to the nearest site where the Internet Backpack could be stored securely (Cinquantenaire School located a few kilometers away). Presently, we are at the stage where we are seeking a LoRaWAN signal booster on the modules. When accomplished, the satellite connection of the Internet Backpack proves to be the best option to transfer data since other cellular networks are presently unavailable.

V. CONCLUSION

We discuss the preliminary stages of deploying a communication system for monitoring sensors in a region with low Internet penetration. This system is designed based on previous work that employs an edgeware model which aggregates heterogenous and distributed wireless resources to provide transparent services of various applications, systems and devices. The present application explores the vulnerabilities of this system under extreme conditions.

Understanding the efficacy of the Internet Backpack as a connectivity and communication device will assist in future disaster preparedness and mitigation.

The effects of disasters are frequently exacerbated due to poor physical infrastructures, remoteness of impacted areas, limited awareness among populations, and lack of human, economic, technical and other capacities needed to respond. Preliminary findings from CO_2 monitoring at Mt. Nyiragongo Volcano suggest that post-disaster resiliency for communities, particularly those which are socially and economically vulnerable, can be enhanced with use of the Internet Backpack. The next deployment, after determining the best approach to safeguard the system, in addition to deploying the CO_2 sensor prototype at the GVO in Bulengo is placing sensors in existing fractures across Goma, to observe changes in CO_2 levels around the city.

REFERENCES

[1] The World Bank Group, World Bank Open Data, 2019. [Online]. Available: https://data.worldbank.org/

[2] Hootsuite, Digital 2019: Democratic Republic of the Congo, vol. 01, January 2019. [Online]. Available: https://www.slideshare.net/DataReportal/digital-2019-democratic-republic-of-the-congo-january-2019-v01

[3] Central Intelligence Agency, The World Factbook, Africa: Democratic Republic of the Congo, 2019. [Online]. Available: https://www.cia.gov/library/publications/the-world-factbook/geos/cg.html

[4] B. Smets, D. Tedesco, F. Kervyn, A. Kies, O. Vaselli, and M. M. Yalire, “Dry gas vents (“mazuku”) in Goma region (North-Kivu, Democratic Republic of Congo): Formation and risk assessment,” Journal of African Earth Sciences, 58(5), pp.787-798, 2010.

[5] L. W. McKnight, W. Lehr and J. Howison, “Coordinating user and device behavior in wireless grids,” in Frank H. P. Fitzek, Marcos Katz, Eds. Cognitive Wireless Networks. Concepts, Methodologies and Visions Inspiring the Age of Enlightenment of Wireless Communications. Springer Verlag, pp. 679-697, 2007.

[6] L. W. McKnight., “Open Specifications Model v0.3: Wireless Grids Internet of Things (WiGIT) Technical Requirements”, 2015.

[7] J. Marsden, J. Treglia, L. W. McKnight, “Dynamic emergencyr response communication: The intelligent deployable augmented wireless gateway (iDAWG),” in *Proc. 2012 IEEE, International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support*, pp. 279-286, 2012.

[8] J. Treglia, L. W. McKnight, M. Venkatesh, T. Bose, H. Volos, J. V. Aardt, D, McKeown, S. Mishra, and M. Lee, “Social emergency response technology policy”, presented at *the 39th Research Conference on Communication, Information and Internet Policy*, Arlington, VA: TPRC, 2011.

[9] L. W. McKnight, D. Smith, A. Salas-Castro, and L. Belli, “Sustainable development by Internet Backpack in the Democratic Republic of the Congo, Liberia and Costa Rica, in *Proc. IEEE GHTC*, pp. 118-124, Seattle, Oct. 18-20, 2019.

[10] 2018, *Imcon’s Internet Backpack Empowers The World: One Connection At A Time.* Retrieved from https://imconintl.com/product/iot/

[11] T. Brooks, “Edgeware security risk management: A three essay thesis on cloud, virtualization and wireless grid vulnerabilities,” Syracuse University, The School of Information Studies, Dissertations - ALL. 39, 2013