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COMPUTER SCIENCE

Community-Centred Network Management for Community Wireless Networks (CWNs)

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Abstract

Community wireless networks (CWNs) have emerged as a viable solution for addressing connectivity challenges in remote areas by fostering resource sharing and local infrastructure management. The complexity of technical network management hinders the sustainability of CWNs, despite their significance in connecting underserved communities. Advancements in deployment have not fully addressed the ongoing reliance on external expertise for maintenance, posing a significant challenge. Training, while a potential solution, proves costly and faces difficulties in ensuring long-term self-sufficiency among community members. This dissertation aims to contribute to the sustainability of CWNs by identifying the challenges faced by local network operators and simplifying the technical network management process. Drawing from the literature on Information and Communication Technologies for Development (ICT4D), which emphasises designing with and for communities, an investigation into CWN management interfaces was conducted. This research employed a community co-design approach, focusing on CWNs in South Africa and India, to identify the challenges and needs of community wireless network local operators. Utilizing contextual inquiry, semi-structured interviews, co-design workshops, and observations, qualitative data on the current challenges faced by CWN management tools was gathered. Through workshops and prototyping sessions with stakeholders in India and South Africa, network operators and users were engaged to reimagine and co-design Network Management Interfaces (NMIs) that empower local network operators to monitor and manage their networks effectively, thereby reducing dependency on external support. Findings highlight diverse network management approaches, revealing difficulties in technical capacity building, troubleshooting, and prototyping. Designing NMIs with local network operators' insights and skills is crucial for CWN sustainability. This dissertation outlines design opportunities to improve network management interfaces for CWNs, fostering network resilience for critical infrastructures.

0.1 List of Publications

Here is a list of publications obtained during the course of my masters studies:

- Iitumba, Ndinelao and Shinde, Siddhant and Ortega, Deysi and Bagalkot, Naveen and Verdezoto, Nervo and Manuel, Ganief and Dinesh, TB and Densmore, Melissa (2023) Reconsidering Network Management Interfaces for Communities, Proceedings of 4th African Human Computer Interaction Conference (AfriCHI 2023), 27 November - 01 December 2023, East London, South Africa,, Reconsidering Network Management Interfaces for Communities, 23, 1-12, University of Cape Town.
- Iitumba, Ndinelao and Shinde, Siddhant and Ortega, Deysi and Bagalkot, Naveen and Verdezoto, Nervo and Manuel, Ganief and Dinesh, TB and Densmore, Melissa (2023) CoLRN - A Community-Based Vision for Local Resilient Networks, Proceedings of ACM SIGCAS/SIGCHI Conference on Computing and Sustainable Societies (COMPASS 2023), 16-19 August 2023, Cape Town, South Africa, CoLRN - A Community-Based Vision for Local Resilient Networks, 55, 1-4, University of Cape Town.
- Iitumba, Ndinelao and Mthoko, Hafeni and White, Keegan and Madzena, Mapule and Drummond, Tristan and Johnson, David and Densmore, Melissa (2023) Networked Micro-Services: Empowering Local Micro-Enterprises in a South African Township through Community Wireless Networks, Proceedings of EAI INTERSOL 2023 - 6th EAI International Conference on Innovations and Interdisciplinary Solutions for Underserved Areas, 16-17 September 2023, Flic en Flac, Mauritius, 34, 1-24.
- Shinde, Siddhant, Ndinelao Iitumba, Naveen Bagalkot, Melissa Densmore, and Nicola J. Bidwell. "Research with Communities: Learning with Experts from Global Community Network." In Proceedings of the 6th ACM SIGCAS/SIGCHI Conference on Computing and Sustainable Societies, pp. 145-148. (2023).
- Densmore, Melissa, T. B. Dinesh, Naveen Bagalkot, Nervo Verdezoto, Ndinelao Iitumba, Siddhant Shinde, and Deysi Ortega Roman. "CoLRN: A community-based vision for local resilient networks." (2022). <https://www.itu.int/itu-d/sites/connect2recover/wp-content/uploads/sites/31/2022/11/C2R-RC-5-A-community-based-vision-for-local-resilient-networks-221122.pdf>page15

0.2 Acknowledgements

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0.3 Use of Artificial Intelligence

In the process of writing this dissertation, I have leveraged ChatGPT to refine the grammar of my content. I would input a paragraph and prompt the model to correct any grammatical errors within it. By utilising ChatGPT as a valuable tool for grammar correction, I have been able to streamline the writing process and improve the clarity and precision of the dissertation.

0.4 Acronyms

CNs Community Networks

NM Network Management

NMI Network Management Interfaces

CWNs Community Wireless Networks

HCI Human Computer Interactions

ICT4D Information Communication Technology for Development

UCD User-Centred Design

QR Research Question

WNM Wireless Network Management

UISP Ubiquity Internet Service Provider

UNMS Ubiquiti Network Management System

IEEE Institute of Electrical and Electronics Engineers

OV Ocean View

DDhills Devarayanadurga

SOWUG Soweto Wireless User Group

ISOC Internet Society

APC Association for Progressive Communications

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Chapter 1

Introduction

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A group of community members and community leaders from Ocean View in South Africa came together to discuss the needs of the community for the youth and school learners. They discussed the community's requirements for access to the internet and the hosting of local content. They approached network engineers from a local firm and decided to collaborate on a community wireless network development project. Together, they sought funding for equipment, and the network engineers assisted with the design, implementation, and deployment of the CWN. After the successful deployment, the network engineers handed the CWN to the community leaders and continued to train the community members interested in managing the network. They conducted training workshops and received technical support from the network engineers. The community fully relies on the network engineers for

network maintenance and troubleshooting. Despite significant efforts, an unpleasant reality became evident: the CWN encountered substantial challenges in terms of sustainability due to network maintenance and troubleshooting issues.

This tale introduces an investigation into the core difficulties faced by local network operators when managing their CWNs. It provides the setting for an investigation into the management of CWNs by local network operators. My objective is to analyse the experiences of local network operators in order to uncover valuable information that can inform the improvement of network management and CWN sustainability by local network operators.

1.1 Bridging the Digital Gap: Internet Evolution, Disparities, and Community Initiatives

The Internet has brought about a technological revolution by enabling the interconnection of computer networks worldwide, granting access to vast repositories of information. With an estimated user base of 4.5 billion individuals in 2020, the Internet serves as a versatile medium for a wide array of purposes relying on information, spanning from human communication through platforms like social media, electronic mail, chat rooms, and newsgroups to the transmission of audio and video content [13]. Moreover, it facilitates access to digital resources via the World Wide Web [29]. In addition, the Internet has fostered the expansion of e-commerce, encompassing not only online-based entities but also traditional brick-and-mortar establishments that conduct substantial proportions of their operations in the digital sphere [45, 16, 37, 126].

However, in spite of the advancements in Internet infrastructure development within Africa since the mid-1990s and the efforts of visionaries such as Nii Quaynor, sub-Saharan Africa still trails behind the rest of the world, evidencing a mere 18 percent Internet penetration rate—significantly lower than the global average of 30 percent [109]. The lack of a critical mass of tech-savvy people and a lack of professionals working in software development, application design, and tool creation use are contributing factors to this digital divide [114]. Moreover, a lack of strategic technology investment exacerbates the situation, with the region focusing predominantly on technology consumption rather than production. This discrepancy continues to expand, allowing established global corporations to consolidate their positions, thereby impeding efforts to stimulate local production and innovation.

While often described as a "network of networks," the Internet's origins trace back to the 1970s in the United States, though its transformative potential didn't fully emerge until the early 1990s [69]. As an information-dependent medium, the Internet

remains accessible to anyone connecting to one of its constituent networks [65]. However, despite the positive impact of accessible Internet connectivity on remote communities, affordability remains a persistent barrier [127]. This financial divide further accentuates the disparity between those who can and cannot afford Internet access and related devices [127]. The provisioning of Internet connectivity to remote communities through Community Wireless Networks (CWNs) has emerged as a pivotal avenue for driving socio-economic progress [11]. Achieving this goal hinges on the establishment of sustainable public Wi-Fi infrastructures tailored to such communities [88]. 1

1.2 Motivation

CWNs have the potential to empower underserved populations and foster digital inclusion by aggregating demand for internet services and enabling communities to locally build and manage their network infrastructure. However, despite the numerous benefits these networks offer, there are significant challenges in sustaining CWNs and effectively managing their network infrastructure. The motivation behind this dissertation stems from the realisation that while CWN deployment has become more accessible, the level of technical expertise required to maintain these networks often perpetuates reliance on external assistance [50]. Traditional training approaches may initially address this issue, but the practicality of constantly relying on trained network administrators on-site becomes cumbersome, hindering the long-term sustainability of CWNs [119]. As a result, community members struggle to fully embrace self-reliance in operating network management interfaces, posing a significant obstacle to network resilience and overall critical infrastructure resilience.

Drawing upon the existing Information Communication Technology for Development (ICT4D) literature, which emphasises the significance of designing technologies with and for local communities [105], this thesis seeks to investigate network management for community networks and empower local network operators and community members by placing their insights and skills at the forefront of CWN network management. By doing so, I aim to enhance the sustainability of CWNs through community empowerment and active involvement in network administration by local network operators.

The motivation further derives from the need to address the scarcity of in-depth qualitative studies that comprehensively explore the challenges faced by CWN users, prospective network operators, and existing local network operators. By engaging with stakeholders from diverse CWNs in South Africa and India, this research seeks to provide a comprehensive understanding of their experiences, visions, and the underlying complexities of network management. Building on the insights gathered

through interviews and workshops with CWN stakeholders, I aim to propose design improvements for network management interfaces that cater to the specific needs and capabilities of local network operators.

1.3 Problem Statement

Marginalised communities are increasingly deploying Community Wireless Networks (CWNs) to address the Internet connectivity gap [50]. However, they are constrained by challenges related to sustainability and effective network management [104]. Despite improved accessibility in CWN deployment, the required technical expertise needed for maintenance often results in continued dependency on external support, hindering the self-reliance of local communities in network administration [13, 119, 105]. Conventional training methods offer initial support, yet the perpetual reliance on trained network administrators becomes impractical and costly in the long term, impeding effective network management [11, 50, 51, 106]. This dissertation addresses the network management challenges faced by local network operators and community members when sustaining their Community Wireless Networks (CWNs). The objective is to discover and overcome these challenges by co-designing an accessible network management tool tailored to the distinctive contexts of CWNs, understanding the needs of local network operators, and promoting self-sufficiency in community-driven sustainable network management.

1.4 Research Questions

This research recognises the crucial role of community members, not just as users and managers of the CWNs but as experts in the local socio-cultural context. I ¹seek to empower communities to leverage wireless communications on their own terms, understanding that greater empowerment at the local level will lead to more vibrant participation in network management. In this research, I invited CWN stakeholders to reflect on their network management experiences. In addition, this project evaluated the current level of local network operators' challenges to CWN's sustainability. The challenge is the management of the network. Skill in networked systems is necessary to operate the current hardware and software infrastructure of CWN. Consequently, community wireless networks (CWNs) face difficulties in recruiting and retaining operators from their own communities, leading to a continued and unsustainable dependence on skilled network managers. This research proposes building a set of community-centred network management tools to simplify network management in CWN operations. Current research on network management interfaces

¹Throughout this dissertation I will use "I" to refer to the author of this research

primarily targets experts, with some exceptions for research on home networking. However, research on the sustainability of CWNs highlights network maintenance and a lack of expertise as key factors in their success. This research sought to answer the following questions:

- RQ1 What challenges inhibit CWN operators and community members from managing their CWNs?
- RQ2 How do CWN operators envision the management of CWNs?
- RQ3 How can community-based co-design be applied to design a CWN management interface that allows semi-skilled and non-experts to manage their CWNs?

For these RQs, CWN operators include both current CWN operators and people that are considering the deployment of CWNs, as well as prospective CWN operators.

To address RQ1, this study conducted a contextual inquiry and co-design study, using interviews and an initial workshop with participants that are current network operators and community members from existing CWNs such as Inethi, Mamaila, and VNET to better understand the current use and challenges encountered.

To address RQ2, this study conducted in-depth observations during co-design workshops and interviews. The set-up of co-design workshops is a space where CWN operators can co-design Network Management Interfaces (NMIs).

RQ3 raises issues of ownership and engagement. Through working together during workshops and interviews with community members, this study deployed the RadiusDesk network management interface, as most community and local experts preferred the platform. Local network operators made contributions to the design of the NMIs through co-design activities that will result in building a better network management interface that will be deployed in the future. In the community engagement co-design activities, I operationalised ownership and engagement in discussions of the better NMIs through designing and testing.

1.5 Objectives

The objectives of this research are as follows:

- To examine and analyze the network management platforms used by existing existing CWNs
- To identify the needs and challenges that the existing CWNs face in managing these networks.

- To assess how the selected communities, manage and maintain their networks.
- To evaluate the best practices that can help community members control their network.
- To co-design a network management interface for CWNs that will be suitable for local semi-skilled network operators.

1.6 Significance of the Study

This study holds significance in the field of HCI, particularly in the area of community wireless networks (CWNs), by addressing the pressing need to simplify network management for local network operators. In remote and marginalised areas, where CWNs serve as crucial connectivity solutions, the effective management of these networks is often hindered by technical complexities. Simplifying network management for local operators not only fosters self-sufficiency but also enhances the long-term sustainability of these networks. This study's outcomes have the potential to significantly bolster the resilience and sustainability of CWNs, ensuring their continued operational effectiveness and relevance within these underserved communities.

Moreover, the accessibility of network management tools specifically tailored for CWNs and local network operators presents an opportunity for the democratisation of connectivity in remote areas. By making the management interfaces easy to use and user-friendly, this study aims to empower local operators, enabling them to navigate and manage these networks more effectively. This initiative not only promotes the self-reliance of these communities but also aligns with the broader goal of bridging the digital divide by ensuring sustainable and accessible Internet connectivity.

1.7 Delimitation

The study is centred around network management within CWNs and is specifically limited to exploring and understanding the experiences, challenges, and co-design of network management interfaces for local network operators. While acknowledging the broad spectrum of network management, this research focuses on discovering the technical challenges faced by local operators when managing CWNs. This study approach involves the design and evaluation of network management interfaces that empower semi-skilled and non-expert individuals to oversee and maintain community networks. It is important to recognise that alternative approaches, such as exploring various technical or administrative facets of CWNs, could contribute additional dimensions to the understanding of network management. However, this study's

primary emphasis remains on simplifying network management tools to promote the self-sufficiency of local operators within community wireless networks through user-centred design (UCD).

1.8 Thesis Outline

This section outlines the organisation of the remaining part of this dissertation:

Chapter 2: Background and Related Works - which explores CWNs, community networking history, network management challenges in developing regions, existing interfaces, case studies, and limitations within CWNs.

Chapter 3: Methods - which details the research design, participant recruitment, the methodological approach in three phases, ethical considerations, and limitations of the methodology.

Chapter 4: Findings: Network Management Practises from Interviews - provides insights from interviews on participant backgrounds, roles in CWN management, challenges with existing platforms, hardware diversity and their troubleshooting strategies.

Chapter 5: Findings: Network Management Community Based Co-Design - shares findings from co-design workshops.

Chapter 6: Findings: Network Management Outcomes Based on Deployment - shares findings from deployment workshops and evaluations.

Chapter 7: Discussions - engages in discussions around diverse hardware design, reconciling network-centred and community-centred models, future design agendas, remote network management, centralised versus decentralised management, and advocating for community-owned networks.

Chapter 8: Conclusion and Future Work - synthesises findings, recommends future research directions, and proposes potential areas of exploration and development in the CWN domain.

1.9 Chapter 1 Summary

This chapter introduced the study and established the study's context. The research problem statement, the research objectives, the research questions, the study significance and the thesis outline. The following chapter goes over the background and related works.

Chapter 2

Background and Related Work

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This chapter explored what other researchers have discovered about community wireless networks. The chapter looks at how community networks are set up, the different designs used, and how they bring Internet access to areas that didn't have it before. Various studies have investigated creating, starting, and keeping these networks running [92, 91, 111, 105]. The focus here is on past efforts in community networks, the problems and limitations faced by wireless networks in developing regions, past studies on managing networks, and the tools used for network management [119, 118, 92, 13]. I have published some parts of this related works in the AfriCHI paper and CoLRN Report [60, 36].

2.1 Community Wireless Networks

Community Wireless Networks (CWNs)

are organisations or movements dedicated to providing free, subsidised, or cost-effective Internet access through wireless means, specifically tailored for and by local communities [95].

A mounting number of underserved rural and township communities, in collaboration with information technology experts from universities and various NGOs, have successfully initiated open IP-based community wireless networks. These networks contain diverse wireless access points interconnected to form wireless mesh networks [122]. By incorporating locally hosted servers, CWNs serve to empower marginalised communities by providing them with Internet access and localised services [26]. Setting up CWNs is mostly done in places that do not have any existing technology infrastructures. This is because they need to use resilient wireless networking technologies because there is not a lot of electricity available and there is not any standard IP service provider wiring [96]. In contrast, urban areas have witnessed progressive Internet connectivity with expanding bandwidths, while rural and marginalised communities continue to rely predominantly on traditional cellular technologies.

CWNs hold the potential to support the establishment of smart cities through the connectivity they extend to the previously unconnected, ultimately enhancing the socio-economic well-being of community members [97, 57]. However, the journey towards implementing and sustaining CWNs is fraught with challenges, ranging from financial limitations to human resource constraints. In addition, policy restrictions imposed by telecommunications and Internet Service Providers (ISPs) pose obstacles for marginalised communities striving to sustain CWNs [82, 115]. In recent years, interest in deploying CWNs has surged, with successful implementations in African countries such as South Africa, Kenya, and Zimbabwe, as well as Asian nations like India [115, 107]. Nonetheless, the plans for ensuring the long-term viability of these networks remain deficient. Achieving CWN sustainability encompasses aspects like hardware maintenance and network management by skilled technical operators. Unfortunately, a common pattern emerges wherein technical engineers and researchers assisting communities during the setup phase move on after network testing or pilot projects, leaving communities struggling to uphold the networks' functionality over time [119].

CWNs play a pivotal role not only by enabling communication but also by potentially catalysing development in marginalised regions. They expand the reach of local businesses, health services, and education, transcending geographical boundaries [117]. However, while establishing and deploying CWNs has become more feasible,

the management and sustainability of these networks, along with their associated resources, pose significant challenges for community members to grapple with [13]. Limited financial support, insufficient resources, infrastructure constraints, and a lack of technical expertise all contribute to the complexity of network management. Numerous endeavours to introduce low-cost systems in rural and developing areas have met with failure [13, 117]. The main reason for these setbacks is that the problems that keep networks from being truly sustainable are often not taken into account. These problems include environmental issues, power supply, financial limitations, low technical skills among local operators, and problems with the infrastructure [13]. In marginalised communities, locating individuals possessing the requisite technical skills to oversee the network proves challenging. Furthermore, effective CWN management necessitates abundant resources and technical proficiencies, encompassing the setup and monitoring of wireless connections. Beyond the initial network deployment, ongoing maintenance demands expertise—resources that low-resourced communities frequently lack. Consequently, this research endeavours to collaborate with network managers, local operators, and community members invested in CWNs from projects like Inethi, Zenzeleni, VNet, and other CWNs beyond Cape Town. The goal is to comprehend their network management requirements and devise a network management platform to bolster the management of these community-driven networks.

2.2 CWNs and their Role in Shaping Communities

Community wireless networks (CWNs) have emerged as a compelling response to the pressing need for Internet connectivity in remote regions. Comprising collaborative efforts by community members, CWNs harness airwave telecommunications resources to establish intricate wireless mesh network technologies [112]. These networks are not only instrumental in providing sustainable Internet access but also contribute significantly to the socio-economic advancement of community members. Despite the benefits associated with Internet access, issues of affordability persist, exacerbating the digital divide. The imperative to provide Internet connectivity to remote communities has underscored the importance of CWNs, with projects such as Inethi and Zenzeleni community networks in South Africa taking proactive steps to bridge this gap by deploying community-driven networks that facilitate both connectivity and the sharing of localised content [12, 74]. Given that CWNs are often established in regions lacking pre-existing infrastructure, their reliance on robust wireless networking technologies is evident, compensating for limited access to electricity and conventional IP systems.

The COVID-19 epidemic brought attention to the significant differences in access to the Internet, particularly in poor socio-economic communities [113]. Financial exclusion, uneven infrastructure deployment, and a lack of knowledge and training in digital technologies are the main causes of Internet access issues, according to [71]. This challenge goes beyond the scope of digital justice, embracing the necessity of guaranteeing equitable access to digital infrastructure and services. To promote inclusive dialogues that can benefit the global community, it is imperative to involve populations that have been historically marginalised in offline contexts in discourses regarding Internet access [41]. To tackle these issues, marginalised and remote communities are addressing the problem by establishing Community Wireless Networks (CWNs) under the supervision of communication network specialists [92]. These communities create their networks by utilising resources and securing revenue through contributions or donations. However, managing and working with these community networks' digital infrastructure comes with a number of challenges, such as issues related to power, finding the money to replace equipment and expand the network, getting a backhaul, and managing the networks' technical aspects [40]. In order to construct robust Community Wireless Networks (CWNs) and foster the advancement of diverse and inclusive digital technologies, it is imperative to engage under-represented communities in conversations and design workshops [40].

As a result, communities are taking matters into their own hands and building their network infrastructures to provide locally networked services, bypassing Internet service providers. Previous research has explored the importance of CWNs and alternative network design models to address connectivity gaps in under-represented communities [105, 107, 107]. Organisations such as the Internet Society and the Association for Progressive Communications have also made financial commitments to support the development of CWNs worldwide [41].

However, existing studies on CWNs have primarily focused on technical design, implementation, and sustainability, with an emphasis on financial and technological challenges [11, 92, 40, 3, 20, 18]. Other studies have looked at geographical and gender implications, as well as the infrastructure and politics of community networks [92] [40, 80, 110]. Limited access to network management resources presents additional challenges for community members in maintaining these networks. It is necessary to conduct more research to comprehend how community members view network management, the difficulties they face as CWN operators and community members, and their expectations for CWN management.

This thesis outlines the results of a qualitative investigation carried out with 25 stakeholders at CWN. The study covered virtual interviews with CWNs in South Africa and India, along with face-to-face workshops with stakeholders from two CWNs in South Africa and India. The study sought to reveal the requirements, experi-

ences, responsibilities, challenges, and problem-solving resources of current CWNs in overseeing their networks. The research also investigated optimal strategies for network monitoring and collaboratively developed a network management interface that is well-suited for both existing and potential network operators. This study enhances the current understanding in the fields of HCI and ICT4D by offering a more profound insight into the difficulties encountered by local CWN operators. It provides a perspective on network management and architecture that focuses on the community and aims to give local CWN management more control and authority. The results indicate that community networks depend on varied and impromptu equipment, resulting in the utilisation of distinct network administration interfaces. Moreover, local network operators necessitate either formal or informal training to effectively oversee the network. The objective of the project is to assist local network operators in managing community wireless networks and provide insights for the future development of community networks in the Global South, with a focus on enhancing resilience and inclusion.

2.3 Wireless Network Management for the Developing World

Wireless Network Management (WNM) includes monitoring and managing the network by handling wireless devices (access points and switches) [42]. The routers or access points sort the device traffic by bandwidth usage and transfer data to each device using the appropriate speed for each device type [42]. WNM means having someone or a company solve network troubles in real-time; this someone or company can be a network technician present on the CWN site or have remote access to the wireless network via a network management interface. A networking expert is an individual that has excellent network technical skills or knowledge from training or education [90]. A semi-skilled expert is an individual who has general skills acquired through a specific routine [34]. Novice users are new to network technical tasks, and they understand networks [34]. Having an expert or a company manage the network can be costly. Currently, volunteer network admins, founders, and students manage CWNs using open-source network management tools. Outsourcing network management to experts or companies can be costly. As a result, many volunteer network administrators, founders, and students use open-source network management tools to manage community wireless networks. These tools enable them to oversee and maintain the network with limited resources. However, challenges remain in ensuring efficient network management within community networks, considering the varying levels of expertise and the need for reliable and accessible management interfaces.

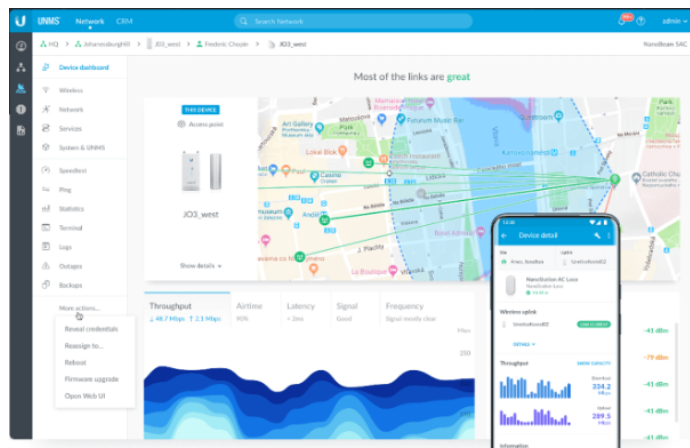


Figure 2.1: UISP is a software application which allows you to manage, configure, upgrade, and monitor all the ISP and provider devices Ubiquiti makes. This is also the commonly used network management interface by community wireless networks

Nowadays, the evolution of community wireless networks in the developing world seems to be taking a fairly different path from the traditional networks I see in technologically advanced countries. Developing countries are adapting to the use of wireless mesh instead of fibre and other commercial broadband alternatives. Network management for community wireless networks is equally important for ensuring that CWNs are effective. Network management for CWNs experiences challenges due to different factors such as power failure, lack of resources, funds, skills, tools, etc. Currently, CWNs use different open-source software to manage their networks. Network experts and technicians are mostly handling the network management of CWNs. The involvement of community members in network management has been slowly adapting in some communities, even though others still depend on network managers. Network management for CWNs has turned out to be vital because Internet access has now become a necessity for developing countries due to its impact on development[131].

2.4 Existing Network Management Interfaces

There are many network management interfaces, such as the Ubiquiti Internet Service Provider (UISP), Stix, Afrimesh Network Management System (NMS), MAYA, RadiusDesk, MeshMan, and ReMesh [4, 15, 39, 78]. UISP offers management for their EdgeMAX, EdgeSwitch, airMAX, and UFiber devices [15, 4, 5]. UISP is accessible to network operators that have purchased UISP devices for free. The system features of UISP include displaying online and offline links, throughput, network

statistics, network logs, signals, frequencies, and monitoring access points. This tool also provides a map presentation of the network connection. The STIX platform, designed for managing emerging large-scale wireless networks, can display data (uptime, active connections, and disconnections) acquired from multi-vendor devices and store log events. Its features include an aspect device manager (abstraction of real hardware), a workflow engine, and a communication manager for communication among Stix services [15]. Unlike UISP, researchers have designed Stix to manage deployed community wireless networks. Also, there is MeshAdmin, an integrated wireless mesh network management platform. The Afrimesh Network Management System (NMS) platform provides service to the village Telco wireless network project that engages with various tools, applications, and devices to support network managers in monitoring and sustaining networks [1]. Unlike the Stix and UISP platforms, the NMS emphasises mobility management, power management, and network monitoring and profiling.

Wireless Internet service providers developed these network management interfaces to ease network management for community networks while keeping the network management infrastructure flexible. However, these interfaces are more suitable for network experts. These interfaces focus more on wireless mobile network mobility management, power management, network monitoring, and profiling for network managers that are technically skilled and are not designed for community members or from a local non-expert perspective [1, 15]. These network management interfaces also require minimum input from community members or targeted users and are designed to assist well-equipped network managers and administrators. Most of these tools are individually not enough to manage a mesh network itself, as they end up requiring the usage of additional other interfaces together [119]. Using different platforms to manage a network causes information and data scattering because each platform has its own database and visualisation interface, meaning that some of its functionalities overlap when other platforms deal with mutual network parameters. Using different network management platforms makes it even more challenging to use and make comparisons between different network management tools. At the same time, it also consumes a lot of CPU and device memory.

2.5 Previous Work on Community Network Management

There are some CWN management systems, such as Khula Tech Network Management System, that was developed by Murithi et al. to assist and support network technicians [85]. This application was combined with the WISP back-end systems of Splynx and Ubiquiti Network Management System (UNMS) to power the back-end

operations as much as possible [85]. When it comes to the repair of networks in rural settings, E.Jang, M. Barela, M. Johnson, et al. explored the idea of "crowdsourcing" and the knowledge and ability of the local community to repair their network. They indicated that local community members are able to solve their network issues if they are allowed and given the means to do so [62]. In this study, community members were able to solve antenna, solar panel, and CPU issues, which demonstrated a hidden skill among locals. If people within a community manage and operate their own network equipment, this will lead to lower operating costs and more sustainable usage of the community network [62].

There has been an increase in the development and deployment of community wireless networks over the years. Communities such as Inethi, Zenzeleni, and Rhizomatica in some remote areas made successful deployments of wireless networks in their community despite other challenges such as lack of electronic devices and infrastructure, lack of experts (technical and social), common power failures, or lack of electricity in the areas, besides securing wireless network infrastructures [106]. These communities' deployments are successful for the reason that, up to date, these community networks are running and benefiting their community members.

CWNs exhibit diverse models, each with distinct operational strategies. Several noteworthy examples, such as the Zenzeleni network, the Kondoa Community Network (KCN), Rhizomatica, the Balsapuerto network, the Hispano-American Health Link Foundation (EHAS), and the Vanuatu Inter-Island Telemedicine and Learning (VITAL) Network, along with studies in urban and rural contexts, offer a comprehensive view of the multifaceted nature of CWNs. In Mankosi, Eastern Cape, South Africa, the Zenzeleni CWN stands out for its innovative approach. Despite the absence of a constant power supply, the community installed solar panels at power access points, delivering high-speed Internet comparable to that in urban areas. This community-owned wireless Internet service provider prioritises cost-effectiveness, social entrepreneurship, and the establishment of a rural digital ecosystem to bridge the digital divide [87, 105].

Similarly, in Tanzania, the Kondoa Community Network (KCN) pioneers the use of television white space (TVWS) technology. Spearheaded by Jabhera Matogoro at the University of Dodoma, KCN employs a grassroots approach to connect rural areas. It not only experiments with TVWS as a viable option for wireless broadband but also strives to connect the unconnected in Tanzania, embodying a bottom-up community network model [38]. Moving to Oaxaca, Mexico, Rhizomatica introduced Mexico's first independent GSM network in 2014. Using community-owned micro-telecommunications enterprises, Rhizomatica connects sixteen communities, emphasising affordability, open-source initiatives, and community workshops to expand connectivity [24].

However, challenges emerge, as seen in the Balsapuerto network, established in the upper Amazon through collaboration among the IEEE, Grupo de Telecomunicaciones Rurales, and volunteers. While successful in technological aspects, insufficient planning for financial sustainability led to a temporary cessation in 2014. Subsequent rebuilding efforts, funded by international research, encountered challenges in restoring local stakeholder ownership, impacting long-term sustainability [81, 79]. In Latin American areas since 2004, the Hispano-American Health Link Foundation (EHAS) has utilised mixed fibre-wireless backhaul, unlicensed spectrum, and long-distance Wi-Fi (WiLD) to enhance voice and data access. EHAS focuses on sustainable and affordable Internet solutions, emphasising community-driven initiatives [99].

Collaborative efforts in remote settings are evident in the Vanuatu Inter-Island Telemedicine and Learning (VITAL) Network. Addressing cellular network gaps in Maewo Island, Vanuatu, VITAL leverages local efforts, collaborating with government offices and international organizations. The project provides satellite Internet connectivity for telemedicine and eHealth, showcasing effective communication systems for healthcare workers in remote areas [50]. Furthermore, studies conducted in urban and rural settings highlight the significance of community involvement in network management. Chetty M. et al.'s study in the UK and the USA emphasises the technical needs and constraints faced by community members managing their networks, emphasising motivations for community participation. In rural Papua, Indonesia, a study emphasises the challenge of sustaining local networks without financial sustainability and external assistance for network management, advocating for a house network management system [49, 54].

2.6 Network Management Requirements

Network management is the method or practice of controlling and operating a network with a network management system. Current network management systems make use of software and hardware to regularly gather, evaluate, and make configuration changes to improve performance [86]. CWN hotspot deployments experience serious problems in achieving consistent monitoring, configuration, and management [43]. Network management is mainly categorised into five diverse areas, which include fault management, accounting management, configuration management, and performance management [83]. Below, I define four areas of network management:

Fault management is an operation to repair a sudden network failure, interference, or error, for example, a no-signal error or an insistently high bit error rate [73, 43]. In this case, the users require the network to be in full operational state after a successful repair. There is also accounting management, which helps network man-

agers track network resources such as access to privileges for users, insufficient use of the network, and some users burdening the network for others [43]. In this case, the users require the network manager to access the accounting information on the nodes and to limit the users manipulation of the accounting information. Since wireless networks use devices such as routers, end systems, and switches that interconnect with other devices, these devices need to be configured to maintain and update data among the interconnected devices for a successful network connection [43]. Network managers are usually authorised to manage configurations. Network reconfigurations are vital for network advancement and fault recovery. In this case, the users are required to be up-to-date with configuration changes [43]. Moreover, performance management deals with managing network capacity utilisation, handling excessive traffic, throughput, and bottlenecks [43]. In this case, the users require their applications to constantly have a good response time and to know the worst-case scenarios of the network. Security management: take care of the storage of encryption keys and passwords and access control of the network [43].

2.7 Network Management Requirements Features:

Identifying high data users, monitoring link up time and speed, checking the status of Internet connections, determining how much bandwidth is currently being used, adding balances for clients, monitoring data usage over the previous hour, day, month, or year, updating splash page messages, whitelisting traffic for free access, adding new users (to services or the network), customising services, and so on are some of the features that are critical for network management and maintenance. This research aims to learn more about community preferences and other features from CWN operators.

2.8 CWNs Known Constraints and Pain Points

The present network costs include the expenses associated with network support for operator training, network implementation, operation, and control, distinct from equipment costs and annual maintenance fees [13]. Maintaining the network and encouraging community members to use the community network can be challenging due to factors such as limited ICT skills, high equipment and maintenance costs, a lack of expertise, and power concerns [106]. The operational issues of community networks encompass the need for cost-effective and enduring solutions for various components of the system, such as monitoring, power supply, and recovery procedures. This study involves a collaboration between universities and community networks, namely FOCUS and Janastu Servelots [125, 98]. Janastu's network spe-

cialists consist of community residents who oversee the network, whereas FOCUS focuses on a collaborative endeavour involving both the university and local experts [36, 59]. Organisations such as APC and ISOC offer training sessions to promote the sustainability of these networks [36]. Nevertheless, the training frequently fails to sufficiently equip community members with the necessary skills for network operation and troubleshooting [60]. Local experts face several challenges in technical training, such as identifying network faults, overseeing users and devices, dealing with financial constraints, acquiring technical expertise, handling power outages, and managing network setup in unfavourable weather conditions [36, 91, 98]. The FOCUS network necessitates the presence of on-site specialists to provide prompt support in the event of failures, whereas Janastu requires assistance with user and device management via a network management interface [36, 60]. Both networks encounter power-related malfunctions and necessitate money for the purposes of expansion, repairs, and infrastructure redesign [60]. In addition, inclement weather can disrupt network equipment, including antennas [60].

2.9 Chapter 2 Summary

Chapter 2 provided a background and related work on community wireless networks (CWNs), taking into account their impact, wireless network management in the developing world, and the existing network management interfaces. This chapter also discussed previous research on a variety of case studies, which helped to clarify the many strategies used in community settings. The chapter establishes network management needs, clarifies key characteristics, and lists known limitations and pain points unique to CWNs, building on earlier research efforts. This thorough investigation provides a strong basis for the next investigation of appropriate network management interfaces. As a guide, the chapter presents a clear summary of the key factors influencing the field of research and offers insightful information about the dynamics of community-driven networks. The following chapter provides the methodology of this research.

Chapter 3

Methodology

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I have published some parts of this methodology in the AfriCHI paper and CoLRN Report [60, 36].

3.1 Research Design and Philosophy

This study employed a community- and user-centered design (UCD) approach, emphasising the practice of prioritising the community and users in the design and development process of a product tailored for their specific needs [108]. This method allows participants from the community and users' feedback, contributions, and opinions to influence the design of the final product. UCD promotes local ownership towards community-based tasks, which places the interests of community members on concepts such as responsibility, power, and control towards community assets [128]. This research adopted a qualitative approach, analysing participant perspectives to comprehend the 'what, where, when, or who, why, and how' aspects of decision-making. By concentrating on these elements, the qualitative approach assists in identifying challenges and experiences associated with community-led network management [2, 121]. This methodological choice aligns with the insights presented by Zewski et al. (2020), indicating the significance of qualitative approaches in delving into the deeper layers of decision-making processes not just what, where, when, and who [121].

For this research, I am working with rural and township settings; for example, Janastu and Mamaila CWNs are located in rural areas, while Inethi, Soweto Wireless User Group (SOWUG), and VNET are located in township areas. The UCD method helps to customise the solution for the community and its users to ensure that the solution meets the user's environment and living circumstances in marginalised communities. Community and user-centred design benefit the community by helping HCI researchers understand the needs and preferences of the users. This user experience will assist in building the features of the platform and reaching the goals of this research and the community. In addition, community and user-centred design are built upon an unambiguous understanding of community members, their tasks, and environments. This method also allows the solutions to be user-centred and evaluated by the users' experiences [75]. The participants will be involved in the design and development method, which is iterative. The users require a platform that is easy for them to use because they are part of its design [123]. Community and user-centred design is the right method that suits this research because the community wireless network is a community entity that is shared among the community members that need equal access to the internet. Therefore, the participation of users in this research is a requirement to ensure that the design and development of the network management platform for CWNs are based on users' needs and preferences.

Semi-structured interviews were employed in the study since they are non-standardised and are commonly used in qualitative analysis to answer RQ1 (What challenges inhibit CWN operators and community members from managing their CWNs?) and

RQ2 (How do CWN operators envision the management of CWNs?). In addition, to achieve the objectives of this research, which are to explore the current network management interfaces for existing CWNs in South Africa and India, to examine and analyse the existing platforms of Inethi, VNET, Mamaila, and SOWUG network management interfaces, to identify the needs and challenges that the existing CWNs face in managing these networks. Utilising a qualitative research design, we employed semi-structured interviews to investigate the experiences of local network operators and the issues faced by communities in managing their identity networks when sustaining CWNs. Interviewing is a versatile and potent method for capturing individuals' perspectives and interpretations of their experiences. To acquire the skill of conducting semi-structured interviews, one must go through six distinct stages: (a) choosing the appropriate interview format; (b) establishing ethical principles; (c) formulating the interview protocol; (d) carrying out and documenting the interview; (e) refining the interview protocol [102]. The selection of semi-structured interviews as the optimal approach for this study was based on their capacity to facilitate the modification of interview questions. Additionally, they enable the interviewer to thoroughly investigate and extract answers that are highly pertinent to the study [67].

Qualitative data was obtained through interviews carried out with local network operators and prospective local network operators from the different CWNs in South Africa and India.

3.2 Stakeholders and Participant Recruitment

The involvement of stakeholders assists with maximising participant recruitment for better participation [31]. At the beginning of this study, I was invited by a stakeholder from Inethi CWN from Ocean View to attend the School of CWN training that was happening for a week in Cape Town. I honoured the invitation, and I facilitated participant recruitment for this study at the CWN training as I found different local network operators from different CWNs in South Africa. I purposefully invited community participants and community wireless operators per site and used different methods for data collection to get insights into their everyday challenges using and managing community network platforms. I chose these participants because they are affiliated with existing active community wireless networks. They are also involved in leading and assisting other community members with network management activities. In addition, they also take part in solving the connectivity issues that might occur on the network. Participants were selected from existing CWNs in South Africa and India, mainly Inethi OV CWN, VNET Khayelitsha CWN, Mamaila CWN, Soweto Wireless User Group (SOWUG) CWN, and Janastu Servalots

CWN. The managers or leaders of these CWNs chose the community members who would participate. Each participant was required to own a personal computer or a smartphone to participate in this research.

The classes of users within a CWN that participated in this research are defined as follows: A remote expert network manager is someone who has appropriate or excellent network skills [77]. Remote expert managers handle most technical network problems by replacing devices, doing installations and configurations, troubleshooting the network problems, and setting up the networks. However, they are not based on the site [77]. While local semi-skilled network managers and operators have average technical network skills, they work closely with the remote expert managers and can handle network troubleshooting, installations, and sorting out user problems, but they still rely on remote expert network managers. Lastly, prospective local network operators or non-expert end users are CWN users that have a basic understanding of networks, and they rely on local semi-skilled network managers or local network operators for their network problems [77].

3.3 Research Context

As mentioned before, this research project spanned across two diverse countries, South Africa and India, with a focus on community wireless networks (CWNs). In South Africa, the study site was the Inethi Network, located in Ocean View, approximately 30 kilometres outside Cape Town. Ocean View is a semi-urban township with a vibrant community wireless network that not only provides internet access but also hosts essential local services. Another significant South African participant was the Mamaila Community Network (MCN) in Limpopo, Roerfontein, which originated in 2019 as a pilot project testing the feasibility of establishing a WiFi network. The Soweto Wireless Users Group (SOWUG) in Soweto, Johannesburg, initiated in 2010 as a non-profit organisation, also played a crucial role in this research. Moving to India, our research included the Janastu COW mesh in Devrayandurga, South India, where Janastu has set up a lab with a mesh network known as Community Owned Wireless Mesh (COW mesh). Additionally, the Maya Health COW KII in Channapattna, associated with the Movement for Alternatives and Youth Awareness (MAYA), added a valuable perspective to our cross-cultural investigation. Lastly, VNET in Khayelitsha, South Africa, stood out as a mesh community network with WiFi access points, contributing to the rich tapestry of our research findings.

3.3.1 CWNs Governance, Structure and Technology

This subsection describes some of CWNs discovered at the time of this study, contexts for each CWN, offering insights on governance, structure, and hardware as gleaned from our interviews. Our workshops and fieldwork took place primarily with two CWNs in India and one in South Africa, but I also conducted interviews with operators of additional CWNs in South Africa (Refer to table 3.1).

- Inethi Network (Ocean View, South Africa)

In South Africa, our site is in Ocean View, about 30km outside Cape Town. Ocean View is a semi-urban township community that has a deployed community wireless network that supports the community with access to the Internet and hosting local services. In contrast, Focus is a community-owned wireless network deployed in Ocean View in Cape Town, South Africa. The Focus community network project was a collaborative project by the HCI and ICT4D researchers from the University of Cape Town and the OVCOMM Dynamic, also referred to as the Ocean View directors, that are residents from Ocean View. Most residents from Ocean View are bandwidth-constrained due to the non-affordable prices of mobile data and WiFi packages. The Inethi network infrastructure is setup only in some parts of OV community, at the time of this study they had 9 mesh setup with 20 access point, while they would actually need about 300 access point setup to cover all the area of OV.

- Janastu COW mesh (Devrayandurga, India)

While in India, our site is in Devrayandurga village in South India. In Devrayandurga, Janastu has a lab setup of a mesh network called Community Owned Wireless mesh (COW mesh). Janastu¹ is a software company from Bengaluru in India that operates a community network in Durgadahalli village in South India. Janastu was formed in 2002 by Servalots as a collective and non-profit organization that focussed on supporting other communities and non-profit organizations with their needs. Since 2004 Servalots and Janastu have started working on WIFI mesh networks with volunteers and local community members to set up wireless mesh networks. In 1999, Servalots started an initiative called the Pantoto project that focused on developing web software to manage community knowledge.

- Maya Health COW KII (Channapattna, India)

Movement for Alternatives and Youth Awareness (MAYA) is a Karnataka-based non-profit organization established in 1991. MAYA health addresses so-

¹<https://www.apc.org/en/user/1715/>

cial issues of education/vocational training, Healthcare and Livelihoods. Currently, MAYA has two programs- MAYA Health and Livelihood and a newly established community network called: The Community Owned Network Knowledge Infrastructure (COWHKI) project found at <https://mayahealth.net/>.

- Mamaila Community Network(MCN), Mamaila, Limpopo, South Africa

Mamaila Community Network (MCN) started in 2019 as a pilot project to test the viability of establishing a Community Network (WiFi network). In 2019 the pilot provided free Internet for three months in Limpopo Roerfontein, one of the villages under Mamaila Tribal Authority, connecting a church, a school and a Disability Centre. MCN aims to provide affordable Internet access to community members.

- Soweto Wireless Users Group (SOWUG), Soweto, Johannesburg, South Africa

Soweto Wireless User Group(SOWUG) is a community network in Soweto, South Africa. SOWUG started in February 2010 as a Non-Profit Organization that seeks to promote information sharing through wireless communication. Johannesburg Wireless User Group established SOWUG, which provided wireless services through game playing and chatting to friends who have deployed the WiFi networking at their homes.

- VNET, Khayelitsha, South Africa

V-NET is a mesh (Wi-Fi Access Points) community network in a Cape Town township, well known as Khayelitsha. The community network was introduced to provide affordable access to the Internet and offline services in low-income areas in Cape Town. It is also a collaboration between local communities in Cape Town, and the city of Cape Town².

3.4 Data Collection

This research used a qualitative methodology approach for data collection, platform demonstration, and evaluation. The purpose of a qualitative methodology approach is to offer an all-inclusive context on qualitative data for the use, design, and development of the network management interface for CWNs. Qualitative approaches are frequently known to be more flexible and subjective, which makes them more suitable for this research.

During the interviews and workshops, the participants and the researcher discussed the network management experiences of local network operators to identify chal-

²<https://vnet.vpuu.org.za/>

lenges. Challenges identified from interviews were used in the co-design workshops to help better understand network management from a local network operator perspective, brainstorm solutions, and co-design by sketching possible improved network management interfaces. The researcher provided drawing papers or boards and pencils or pens. A maximum of two prototyping sessions were used to draw up designs and choose the best ones.

I carried out interviews with participants from CWNs in South Africa and India. However, I only carried out the fieldwork workshops with one CWN in India and one in South Africa because it was challenging to conduct co-design workshops with all CWNs due to funding, geographical limitations, and the availability of the stakeholders at the time of this research. However, the interviews were carried out with more participants, as they included network operators from additional CWNs in South Africa. This data collection stage took place between June 2021 and June 2022. During that period, I conducted three phases with a total of six workshop sessions.

3.5 The 3 Phases of the Methodological Approach

Below are three steps the researcher took in conducting this research. I opted for the three-phase approach due to time constraints in completing this project. Nevertheless, this three-phase method can be used to identify the problem.

Table 3.2: Timeline of Activities

Activity	Timeline
Participant Recruitment	June 2021 - August 2021
Interviews	November 2021 - February 2022
Co-design Workshops	April 2022 - September 2022
Deployment Workshops	July 2022 - September 2022
Asynchronous Feedback	October 2022 - January 2023
Analysis	September 2022 - July 2023
Interface Development	October 2022 - November 2023

3.5.1 Phase 1: Interviews

In this phase, I focused on understanding the current network management practices and pain points through contextual inquiry and semi-structured interviews for the

identification of key management activities, NM features, and experiences with existing interfaces(See Appendix C). This study interviewed 18 participants (15 from Cape Town and 3 from India), ranging from a combination of network management experts, local network managers or operators, and prospective network operators from Inethi OV CWN, VNET Khayelitsha CWN, Mamaila CWN, Soweto Wireless User Group (SOWUG) CWN, and Janastu Servalots CWN. First, I wanted to learn about the participants’ backgrounds and how they had been involved in wireless network technical training before being associated with their CWN, or network management. Second, I also asked our participants to discuss their experiences with existing network management interfaces and how they used those platforms. Third, I explored how participants got involved with their community network at the management level, their current roles in their CWN, how participants envision simplified network management interfaces, and most importantly, the challenges they face when solving day-to-day network problems. Identifying their challenges, expectations, and experiences with managing their CWNs, specifically with the current NMs that they are using, assists this study with answering RQ1. See details in (Table 3.1) under phase 1. The insights obtained from these interviews are presented in Chapter 4.

Question Number	Interview Question
1	Tell me about Yourself?
2	Do you have access to the internet? How do you access the internet?
3	When/how did you start getting involved with your CWN at management level?
4	What role do you play in your CWN?
5	Can you set up a network?
6	Have you used any network management platforms before?
7	How much do you know/understand about the community wireless network? (Understand how they perceive the network)
8	Which platform do you use to manage the network? / Which platforms if there are many?
9	What challenges do you face when managing the network?
10	Which resources do you consult when fixing/monitoring your network to understand what you are dealing with?

Table 3.3: Shows the interview questions of this study.

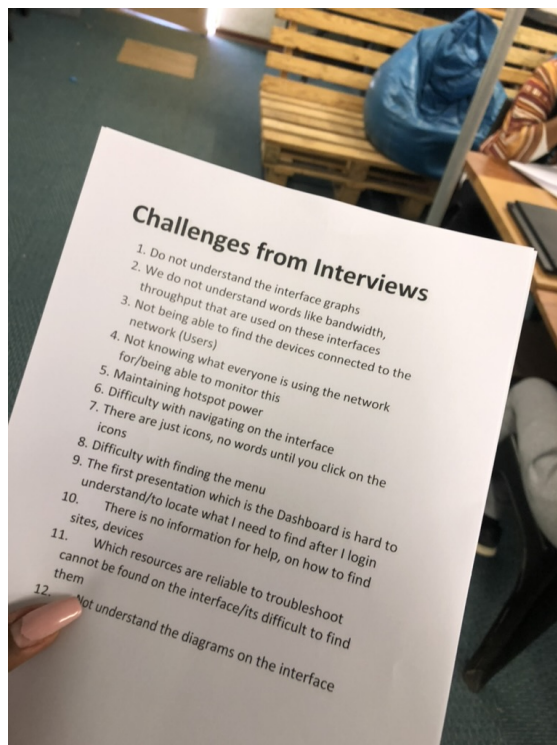


Figure 3.1: This image shows the early findings from the Interviews during Phase 1 of this research. They were discussed and validated in Phase 2 by both Ocean View and Devraynadurga sites.

3.5.2 Phase 2: Co-Design Workshops

During this phase, I conducted one workshop with 15 participants in Ocean View, South Africa, and one workshop with 5 participants in Devraynadurga, India, following the same workshop protocol (See Appendix D). See details in Table 3.1 under phase 2. I intended to educate participants about network management through workshops by first examining their comprehension, attitudes, perspectives on network management, and current CWN management practices. This was aimed at co-designing network management interface prototypes. The primary goal was to engage in discussions concerning NMIs, rating them, and enhancing their features based on the suggestions and views provided by the participants. The co-design methodology was instrumental in capturing the challenges associated with existing NMIs and generating user-centred solutions. Collaborating with the participants and deliberating on NMIs not only facilitated a deeper understanding of the existing challenges but also fostered community engagement and a sense of ownership in the final co-designed NMI. Collaborating with participants to co-design an NMI



Figure 3.2: First Workshop Activity: Identifying, discussing and relating to challenges from Interviews

aimed at significantly contributing to answering RQ3; additionally, the participants were observed while responding to questions and working within their environments.

Workshop Activity 1: Relating to Challenges from Interviews

The aim of this activity was to validate the findings obtained in phase 1 and determine the priorities of the participants. A selected subset of participants was divided into two or three groups. Each group was tasked with providing feedback on the designs developed in phase 1, offering comments and reviews.

Workshop Activity 2: Co-Designing NMI Prototypes

After discussing challenges with participants in Activity 1, I distributed bigger posters that I called the new interface design, printed screenshots of the UISP interfaces (e.g., dashboard, devices, sites, map), sticker pads, marker pens, and colour paper materials for redesigning the network management interface. The participants were divided into 3 groups, with each group having 5 people. Participants discussed the areas they wanted to change in groups, using the challenges that they presented and coming up with new suggestions. Phase 2 focused on prototyping two specific features: the display of active network sites (for instance, OV High School Site 1) and an end-user site map. These prototypes were intended to build on the insights gathered from interviews, further exploring the challenges and experiences faced by the participants.

In Ocean View, I divided the participants into three groups and guided them through a video I created to familiarise them with the Unifi Network Management application used by Inethi CWN. The video showcased various aspects of the Ubiquiti Internet



Figure 3.3: Second workshop activity: Brainstorming and designing network management interfaces

Service Provider (USIP) platform, including the landing page, dashboard, and locating additional information. Following the video session, I facilitated discussions within each group to explore the participants' comprehension of network management and the UISP interface. I encouraged them to delve into the features and visualise how network management played out in their community. The subsequent activity aimed to validate the early interview findings. A list of significant challenges identified during the interviews was shared with the participants, initiating discussions on their perceptions of these challenges and prompting them to identify any new challenges arising after watching the instructional video. Upon identifying new challenges, I provided participants with poster boards and markers to collab-

oratively design a network management interface, sketch user interfaces, or create websites. The co-design workshop protocol was consistently applied (See Appendix D). Following the sketching process, cognitive walk-through sessions were conducted to understand their interface sketches more, where participants elaborated on their interface sketches. Descriptions of their solutions were presented by them for clarification and refinement, allowing for a deeper understanding of their intended designs. Visual drawings created by the participants were to be used for analysis. In addition, participants were asked to present their prototypes to the other groups. During these presentations, participants shared feedback and thoughts on the prototypes developed by other groups. This interactive session facilitated a comprehensive exchange of ideas and perspectives.

Workshop Activity 3: Prioritising the New Changes

After the participants presented their new designs, I gave them pink sticker notes that represented high priority. Using the prototypes produced by participants with different features, I asked them to each place their two sticky notes on features that they considered important to be improved. The top 3 features among all will be used in the phase 3 deployment session. The insights and prototypes obtained from co-design workshops are presented in Chapter 5.

Site	Locality	Community Network Maturity	Key Services	Internet Type	Hardware
Ocean View (Inethi Site)	Peri-urban	Newly established	Currently free; voucher-based	Internet in a box (Wikipedia, Ted Talks, Khan Academy)	Nextcloud, Ubiquiti AC Mesh nodes controlled by Unifi
DD Hills (Janastu Site)	Rural	Since 2014	Since 2021 Free access	Mix, re-claimed routers	Ubiquiti hardware, nanobeams

Table 3.4: Overview of the community networks that participated in the co-design and deployment workshops

3.5.3 Phase 3: Deployment Workshops

For phase 3, I carried out deployment workshops with both sites in table 3.4 following the same protocol (See Appendix E). I started the workshops by revisiting the idea

of network management at each site with our participants and recalling some outstanding outcomes from the first focus group discussions and co-design workshops. See details in Table 3.1 under phase 3. I then proceeded to introduce participants to the Radius Desk (Mesh Desk), the prototype I intended to deploy. In this activity, I showed the participants around the mesh desk interface and showed them different aspects, i.e., how to add access points and users, monitor the devices, and allow participants to ask questions and discuss their thoughts about the interface. The second activity followed this, a live demonstration of adding devices and clients to the interface and allowing participants to ask questions or have a discussion. To avoid interfering with the existing community wireless network infrastructure, I set up a mini mesh network composed of two AC mesh routers, a mini flex switch, and NetGate for live demonstration purposes. During the third activity, I tasked our participants to try adding network devices and clients to the interface themselves. During this activity, I took the participants through the process of flashing devices with the correct firmware compatible with the Mesh Desk software. Lastly, I conducted a feedback session with our participants regarding their experience using the interface, adding devices and clients, and their general thoughts on the interface. The insights obtained from these deployment workshops are presented in Chapter 6.

3.6 Evaluations and Asynchronous Feedback

In this section, I describe the last session of this study. I collected asynchronous feedback from some participants two weeks after the prototype demonstration workshops. I requested feedback from the RadiusDesk (Mesh Desk) deployment and demonstration regarding the challenges they encountered while using the RadiusDesk interface independently and how many times they used it. The feedback's purpose was to track participants' interest and engagement and to motivate changes I could make to the interface. For the asynchronous feedback, I only requested it from 10 prospective and local network operators from Janastu and Inethi/Focus that were present at the deployment workshops.

3.7 Data Analysis

In this research, thematic analysis served as the framework for the analysis of data acquired from a combination of interviews and workshops. This methodological approach allowed us to systematically identify, analyse, and interpret patterns of meaning within the qualitative data, thereby facilitating the extraction of key themes and insights [124]. Through a process of data coding, categorization, and theme develop-

ment, I navigated the complexities of our dataset to breakdown significant findings and gain a comprehensive understanding of the underlying patterns that emerged from the narratives shared by participants [23]. Thematic analysis not only provided a structure for organising the diverse perspectives gathered during interviews and workshops but also enabled us to unveil nuanced connections and uncover valuable insights that contribute to the broader scope of our research objectives on the experiences of local network operators.

Code Number	Interview Codes
1	Number of years spent in CWNs (experience)
2	Training and knowledge for CWN
3	Role/Responsibilities in CWNs
4	Most Common NM Platforms
5	Features of NM on each platform
6	Time to learn manage platforms
7	Reasons for using different platforms
8	Lack of background knowledge
9	CWN as a means to achieve other goals
10	Experience and Challenges with using different platforms
11	Time to build the network
12	Challenges with each platform USIP
13	Monitoring User' Network use
14	Guidelines to use or manage a network
15	Velocity of network
16	Terminology of existing interfaces
17	Historical data in platform
18	Monitoring devices in network
19	Assistance to manage the network
20	Extra resources to consult
21	Devices connecting to a particular hotspot
22	Experience with using UISP platform
23	Participant level of understanding network management: Participant is a local network operator

Table 3.5: Show the codes generated from interview scripts during the analysis process

Our data collection produced 13 hours of recording from 4 workshops and 25 interviews. After each interview or workshop, I transcribed the recordings for analysis. I conducted a thematic analysis by first reading through the transcripts from the

interviews and highlighting the codes (See table 3.5) that formed the themes as they emerged[30, 22]. After grouping all the similar themes, I compared them to the visual drawings and the themes from the workshop transcripts. I looked for specific themes guided by our research questions, mainly tracing local network operators' challenges when managing the network, their experiences, and how community members experience network management. Some of the themes that I focused on included the characteristics of our participants, their current roles in their community network management, their forms of training or education level, how they currently manage the network, the current network management interfaces that they are using, and the resources that they consult when troubleshooting their community wireless network.

3.8 Ethical Considerations

This study conducted online interviews, lasting between 20 and 35 minutes, through video conferencing applications such as Zoom, Teams, and WhatsApp. Before commencing the interviews, the interview guide went through a thorough review of its content and flow errors by sharing it with supervisors. Subsequently, a convergence of the interview questionnaire was performed to ensure its adequacy in achieving the research objectives and addressing the research questions. This approach to ethical clearance and interview preparation laid the foundation for the study's data collection process.

The data obtained from interviews and observations was interpreted and documented in note form. This research data has been duly recorded and is stored on a Microsoft Teams channel, backed up on my University of Cape Town OneDrive platform. Participants were also informed about where I was storing the data.

3.9 Methods Limitations

During the course of this study, the challenge was the COVID-19 pandemic. Depending on the COVID-19 lockdown regulations in effect during the data collection period, interviews were conducted online. Online interviews were only arranged when in-person gatherings were prohibited due to COVID-19 regulations. The researcher had selected appropriate venues for face-to-face interviews, ensuring their duration was limited to one hour or less, contingent on the agenda. However, face-to-face interviews could not happen due to different circumstances such as some participants were from CWNs in Bangalore (India), Johannesburg (South Africa) and those in Cape Town. For online interviews, participants were given the option to choose from various video conferencing tools such as Zoom, WhatsApp, airtime

calls, SMSs, Microsoft Teams, Google Meet, or Skype. Online interviews were approximately 30 minutes in duration and were recorded for subsequent analysis and study purposes. Participants were requested to select their preferred platform, and the researcher assisted them with mobile data.

3.10 Chapter 3 Summary

This chapter provided a detailed research methodology, focusing on the application of the user-centred design (UCD) philosophy in a qualitative study. Employing interviews and workshops, this research engaged participants to gain insights into their experiences with community wireless network (CWN) management and to identify challenges faced by local network operators and community members. This chapter delved into the design philosophy, emphasising the significance of actively involving individuals in the design of network management interfaces (NMIs) to consolidate collective experiences and integrate end-users' perspectives. The research design, stakeholders, and participant recruitment strategies are outlined, providing a foundational framework for the study.

The methodology unfolds through various phases, starting with a contextual inquiry that needs assessment involving interviews (Phase 1). Co-design workshops follow in Phase 2, aimed at affirming and consolidating findings from the initial phase. The third phase involves deployment and prototype demonstration workshops, creating a holistic approach to understanding and addressing the challenges in CWN management. The incorporation of asynchronous feedback, data collection, and ethical considerations are discussed, ensuring a comprehensive and ethical research approach. The chapter concludes with a discussion on data analysis methods and acknowledges the limitations of the chosen methodology, providing a transparent overview of the study's scope and potential constraints. The following chapter provides findings and discussions from the interviews for this research.

Table of Participants				
Phase	Method	Session	Participants	Settings
Phase 1: Contextual Understanding, Needs Assessment, Gathering Requirements	Semi- Structured Interviews	S1	15 participants <i>4 prospective network opera- tors</i> <i>4 network opera- tors</i> <i>4 network users</i>	Ocean View (10) Soweto (2) Khayelitsha (2) Mamaila (1)
		I1	10 participants <i>3 network man- agers</i> <i>7 network users</i>	Channapatna (7) Devraynadurga (3)
Phase 2: Co-Designing the Network Management Interface	Co-Design Workshops	S2	15 participants <i>network users</i>	Ocean View, South Africa
		I2	5 participants <i>2 network man- agers</i> <i>3 network opera- tors</i>	Devraynadurga, India
	Prototype Demo Workshops	S3	8 participants <i>5 network users</i> <i>3 network opera- tors</i>	Ocean View, South Africa
		I3	5 participants <i>1 manager</i> <i>3 network opera- tors</i> <i>1 designer</i>	Devraynadurga, India
Phase 3: Asynchronous Feedback		S4	3 network opera- tors	Ocean View, South Africa
		I4	2 network opera- tors	Devraynadurga, India

Table 3.1: Shows the number of participants from South Africa and India throughout the data collection phases

Chapter 4

Findings: Network Management Practises from Interviews

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Some initial findings from chapter 4,5 and 6 were published and presented at AFRICHI 2023, COMPASS 2023 and in the CoRLN report [60, 36].

4.1 Respondent Distribution and Its Impact on Chapter 4 Findings

In this chapter, it is important to note that the majority of respondents are from South Africa, with a total of 15 participants from different Community Wireless Networks (CWNs) compared to 10 participants from India. Specifically, the South African participants included 4 prospective network operators, 4 network operators, and 4 network users from Ocean View (10), Soweto (2), Khayelitsha (2), and Maimaila (1). On the other hand, the Indian participants comprised 3 network managers and 7 network users from Channapatna (7) and Devraynadurga (3). This distribution contributes to a greater volume of findings originating from South Africa, which may influence the overall emphasis and themes identified in this chapter. The predominance of South African data does not diminish the value of insights from India but highlights the context-specific challenges and solutions that are more prominently discussed. Future research could aim to balance the number of respondents across regions to provide a more evenly weighted comparative analysis.

4.2 Barriers to Community Network Creation and Growth

In the book "Internet for the People by the People," Belli (2017) extensively examines the barriers to creating and scaling community networks. A primary obstacle is the lack of awareness about the potential benefits of Internet access and the possibility for communities to establish their own networks [11]. In addition, financial challenges, particularly in low-income areas, are emphasised, with communities struggling to afford necessary devices and facing additional costs related to power infrastructure due to unreliable or nonexistent electricity grids. The lack of local technical expertise further complicates matters, requiring communities to rely on external assistance for network setup and maintenance [11]. The perpetual cycle of training and retraining is exacerbated by the migration of knowledgeable individuals seeking better opportunities, leaving behind a void of essential skills. The complex web of challenges, including the lack of available telecommunications equipment do-

mestically, further complicates the establishment and sustainability of community networks [14].

Moreover, looking into post/neocolonial power dynamics in African Community Networks (CNs) Nicola Bidwell's survey of 37 Community Networks (CNs) across 12 African countries, the complexity of these networks is explored through the lens of post- and neocolonial power dynamics [19]. Drawing inspiration from Fanon's observations on communication restrictions, the study highlights the importance of political structures, economic resources, and technological standards. Bidwell argues that CNs in Africa form alliances to address gaps left by electric and telecommunications capitalisms, challenging the notion of a 'universal' paradigm and contributing to the emergence of alternative identities in the realm of innovation [19]. This perspective aligns with Luca Belli's emphasis on the need for experimentation and analysis of CNs. Belli emphasises the distinctiveness of CNs, characterised by bottom-up initiatives and community-driven infrastructure development, providing a potential solution to digital divides [11].

4.3 Understanding Practices in CN Management through Online Interviews

This research employed online interviews conducted in India and South Africa with local network operators and prospective network operators from different CNs. The interviews happened online due to COVID-19 restrictions in place during the time of this study. All participants, including local network operators and prospective network operators from various CNs, were subjected to the same set of questions. The focus of this phase of the study was to understand the prevailing practices and challenges in network management through contextual inquiry and semi-structured interviews aimed at identifying challenges, key management activities, and experiences with existing interfaces. The initial objective was to gain insights into the participants' backgrounds, specifically their involvement in technical training related to wireless networks before their association with their Community Wireless Network (CWN) or network management. Subsequently, participants were prompted to discuss their encounters with existing network management interfaces and elaborate on their utilisation of these platforms. The third area of exploration delved into how participants became involved in the management of their community network, their current roles within their CWN, their visions for simplified network management interfaces, and, significantly, the challenges encountered in addressing day-to-day network issues. By identifying the challenges, expectations, and experiences of participants in managing their CWNs, particularly with the current NMIs in use, this study aimed to address Research Question 1. All participants answered the ques-

tions with great enthusiasm. However, most participants from South Africa could not answer all the questions as they did not use NMI or were not aware of the specific platforms being used in their CWNs, but they assisted with the annual CN setup and troubleshooting.

4.3.1 Backgrounds and First Interests in CWNs Stories

During the interviews, each participant spoke about themselves and their interest in community wireless networks. Participant 1 that will be referred to as P1 (and other participants from P1 to P10 as indicated in the table of participants table 3.1) in the rest of this dissertation, said that he is a proud Ocean View community member and educator at the local high school in Ocean View. He also stated that he is one of the founding members of the Inethi community wireless network in Ocean View (OV). He got involved with CWNs 2017, saying that at that time his portfolio into community wireless networks(CWNs) was into network security, and one of the solution that he identified was to establish a local voucher or community voucher or even a community currency, he said,

I realised that for this community voucher to work there is a need for a low cost access to Internet for community members, I was looking into the use of cellular networks but mobile data was too expensive for all of them, I could not find reasonable rates. At this point, cellular networks were not an option” He said that he was then introduced by his friend to a community wireless network expert that was looking forward to setting up a community wireless network in the Ocean View community.

They met up at a local CWN workshop that was held at Ocean View with locals. The network expert was looking forward to establishing a wireless network for the Ocean View Community and at that time he needed a buy-in (support) from the community. Since he knew a lot people within the OV community and community leaders, he agreed to assist with getting support from the community.

Our second participant (P2) happily expressed that he spent most of his time in Soweto connecting people wirelessly and he also recently started using fiber as he is actively consulting with other ISPs around the country, consulting with community networks, and currently in the process of building the community school network content. He got involved in CWNs in 2010 but prior to that he was working for MTN for seven years. He took part in founding the Soweto Wireless User Group with others in 2010. He also joined Johannesburg Wireless User Group, and started assisting building the networks around the year 2015 to 2016.

4.3.2 Insights into the IT Knowledge Landscape of Local Network Operators

This section describes the IT and wireless network technical understanding of local network operators.

Participants expressed that it is challenging for someone to understand and work around solving wireless network technical failures without IT technical education or training in this area. Our participants voiced their professional/career backgrounds and how they manage to work around CWNs without any training.

Our first participant (P1) expressed that he does not have sufficient network technical knowledge, he said

I do not really know much about the network and its technicalities but most of what I know I learned from the university professor that assists me with network management

. He expressed that he has been managing with Inethi network management with the assistance that he gets from the Inethi network deployment partners from the university, he relies fully on them. Since he is based on the site of the network, he usually calls the university network manager to assist. He ends up sharing screen and giving him access control to solve some of the issues that he comes across. P1 also stated that he is recently planning to go for network training that he has registered for with the APC association as he recently joined the APC.

Moreover, P2 outlined that he has been involved in telecommunications for the past 10 years now, and he understands most of the network technical components. Even though, he does not understand everything he said,

I can't say I know everything about wireless technologies and telecommunications technologies, but I am still learning and trying to understand them, it keeps getting better on a daily basis.

When it comes to community wireless networks, he has limited knowledge because he mostly worked with mobile networks and he experiences challenges when fixing wireless networks.

4.3.3 Local Network Operators Roles in CWN Management

This section shares the roles that local network operators play in the network management of their community networks.

Participants played different roles in the establishment and maintenance of their CWN. They stated their roles in the community wireless network they belong to

during interviews. P1 outlined that his role as a director of the InethiCWN was to get the community to support the InethiCWN from the beginning, he later got involved in overseeing the network onsite and assisting community members with connecting to the network. At this point he is involved in the network expansion and identifying the needs of the community besides just having Internet access.

P2 expressed that his role in their CWN is very hectic, as he is responsible for overseeing that the network is stable, there is sufficient power, the network has redundancy and for that their main contractors that help them with the upkeep and running are updated. He has also been training other community members from Soweto on the upkeep and running of the network by teaching them simple troubleshooting solutions. He said,

I have trained other guys in the organization on how to take care of the network as well.

4.3.4 Community Wireless Networks Current NMIs

This section is about the current network management interfaces that the community wireless networks in this study used at the time of this study.

Participants expressed the interfaces that they use to manage their community wireless networks. Participants from OV CWN indicated that they are currently using 4 platforms to manage the network. They are using UNMS platform, which is now rebranded to USIP, The Can-Beams platform, P-f Sense, and MiKroTick. They also indicated that they use Ubiquity (UNMS/USIP platform) to manage the on-board antennas and devices, the Can-Beams platform does the same job as the UNMS platform by monitoring the Can-beams used in the network. They use the P-f-sense platform to monitor the devices, see how many leases and devices are connected to the network. P1 said that they use the P-f Sense platform to monitor the networks throughput that is running through the p-f sense firewall. He said that

so from there than I can see how many unique devices are roaming around our network hotspots, I can also see what the data consumption is at specific times

4.3.5 A User's Perspective on Challenges

This section highlights one of the challenges with using existing network management platforms.

Participants also expressed the challenges they experience when using these platforms to manage the specific aspects of the network. P1 said

It's challenging at times because I find the ubiquity platform easier to work with I understand it much better. I also find it to be a lot more intuitive compared to can beam because I do not have a network background and with ubiquity it handles a lot of the things in the background so it's a lot easier to deploy because initially what we have found with community network, I did not get involved because I studied computer science or network engineering for me to have a network was only a means to an end. Therefore, a lot community networks around South Africa get started in network where the organization they do implement it is not a core function. It is an organisation like Living Hope in my case it was just food guidance and food security but for me to get to what I wanted I had to first help and assist with getting a network up and running. Consequently, within a lot of the other cases that I were exposed to it is the same thing the organization is in health and they just need the platform to reach beneficiaries but now they are also finding themselves in building a community network which you do not have any real understanding of and all you want to do is have a network up and running. It should not be taking you three, four five years of your time to put a network up like this, because the longer you take the more you lose people's interests because it is not their core function to begin with.

4.3.6 Resources Used by Local Network Operators

This section talks about some of the resources that local network operators find useful for network management assistance.

Managing a community wireless network can be challenging when it comes to troubleshooting your network failure errors. There is a need for guidance and resources to assist locals with managing their community networks. I asked our participants during the interview to outline the guidance and resources that they use in order to make successful troubleshoots to their networks. Participants stated that they consult online resources such as YouTube and google to search for answers to their problems by finding similar scenarios on the Internet and trying out different solutions. They also expressed that they are connected to different people in the CWN industry, and they often call each for help.

Participant 1 (P1) said/ I have been exposed to different people since I got involved in community wireless networks, I am in contact with the one of the co- founder of InethiCWN and he always assists me with

troubleshooting and guiding me this far. I cannot properly explain the network problems to him but just when I explain it to him, he understands what is wrong and he always assists by solving the problem or telling me how to solve the problem

Participant 3 (P3) also stated that when he uses online resources such as YouTube, he encounters problems when trying to resolve errors while following a certain tutorial. He said that

I will always follow a tutorial until a certain point where I find that certain elements were not covered, and those small things get me stuck.

Participant 2(P2) expressed that even though the Internet has been quite useful when it comes to assisting him with troubleshooting, the experience of fixing and setting up community networks from scratch is very valuable because you continue to solve same similar problems with the previous solutions that you applied to previous problems. Participant 2 said

The experience comes in handy at this stage once you have done this thing for over two years. Once you have experience a problem that you have encountered two years ago, and you know exactly how you resolved it, On the other hand,you also have other community networks calling you about a problem that you have never come across, yet you can come across it the following weeks.

Participant 4 (P4) also expressed that

experience is a super advantage but guidance and relationships with other community wireless networks is key because those people go through the same experiences that you have. You will never find sometimes even your equipment that you currently use they don't have those answers when you have issues so its issues that are on the ground and that you share as technicians or as people are installers. I share common problem and I have got a database. I have got a knowledge database whereby every scenario is painted across and how its resolved. So that database and just the relationship amongst most technicians will help you go a long way as a community network.

This research also found that participants are interested in upskilling through network by creating tutorials about network development and management on the network that local members of the community can learn and self-training through tutorials. There is need for strategies to make a self-sustainable network for the community when the network is fully managed and maintained by the community. Participants also indicated that they have access to activities and workshops con-

ducted by the Inethi network to train community members, helpline and chatgroup on the network for the community members.

Summary of Challenges identified from the interviews from all participants

- Do not understand the interface graphs
- I do not understand words like bandwidth, throughput that are used on these interfaces
- Not being able to find the devices connected to the network (Users)
- Not knowing what everyone is using the network for/being able to monitor this
- Maintaining hotspot power
- Difficulty with navigating on the interface
- There are just icons, no words until you click on the icons
- Difficulty with finding the menu
- The first presentation which is the Dashboard is hard to understand/to locate what I need to find after I login
- There is no information for help, on how to find sites, devices
- Reliable resources for troubleshooting cannot be found on the interface/its difficult to find them
- Not understand the diagrams on the interface

4.3.7 Ideas for Specific Features for NM Interfaces

This section outlines the specific features and tools that need improvement on existing network management interfaces.

This study found that participants from Ocean View in South Africa also outlined some ideas on specific network management challenges that they experienced, for the features to become more user friendly. Participants mentioned that on the ubiquity interface, the features for disabling and enabling clients or users should be part of traffic shaping. However, it falls under the billing side instead of the monitoring side of things, which makes it difficult for them to find the disabling and enabling features on the interface. They also said that the graphs are not easy to interpret

on the network management interfaces and if the data presented on the graphs can be presented in another simple way.

I do not always get the graphs and it takes me a lot of time to find specific features in the interface. And, what they mean, but I mean that is also on me as well. I also need to make the time to learn what those graphs mean but it is also challenging when you juggle a lot of things you just sit down and that is what you are focusing on. So as part of the network community its challenging when you do not have a nice strong team and you will have to work on a lot of things

Most participants outlined that the important features are Viewing connected devices such as your access points and users in a list format or clear map/graph and having clear access to notifications of devices that are connected and disconnected. They also placed some emphasis on having sites if you manage the network by grouping your devices that this specific location will use this access points and being able to see how many users you have in that location or site. They also mentioned that they need help understanding the interfaces and platforms without training, as they must click everywhere on the interface in search of a specific feature. Because they need to familiarize themselves with most icons and networking categories on the interface that can help lead to a specific feature. They also suggested that having accuracy in reporting disconnected devices would be great because that way, I can know which access points are down at what time and attend to them immediately. They felt the network management tools were already there, capturing most of the data needed to successfully monitor and manage a network. However, they just needed to be more user-friendly.

”The features for disabling and enabling clients or users should be part of traffic shaping, but it falls under the billing side instead of the monitoring side of things.(SA/P1)”

”The difficulty was to understand the interfaces and platforms without any training.(SA/P3)”

”I think our challenge currently is to lose coverage, and the network can be slow, and I do not know how to use the NM interfaces. I have not seen any NM tool.(SA/P6)”

”I think accuracy in reporting disconnected devices will be great because I can know which access points are down at what time and attend to them immediately.(SA/P7)”

4.3.8 Weather Conditions and Power Cuts

This section discusses the impact of adverse weather conditions and power outages on wireless network devices and equipment in the community. The study revealed that the OV community, surrounded by mountains and experiencing windy and harsh weather conditions throughout the year, faces challenges related to signal loss and connectivity disruptions. Participants emphasised that the movement of antennas and routers caused by the wind, and sometimes by interference affecting the networking and prompting troubleshooting expertise. The antennas' movement during bad weather hinders network performance, requiring significant maintenance and resulting in prolonged offline periods. Participants stressed the importance of stable network installation by considering factors such as securing signal poles and implementing security structures to prevent signal interruption during adverse weather conditions, especially on open fields like soccer fields.

In addition to weather-related challenges, participants discussed load shedding in South Africa, characterised by planned government electricity cuts. During the study period, participants expressed frustration over connectivity loss during power outages. The study identified a need for strategic solutions to address load shedding, proposing the installation of generators as power backups. This measure aims to ensure continuous network operation during load shedding, eliminating the need for frequent troubleshooting and network downtime.

4.4 Discussions

4.4.1 Challenges and Complexities in Sustaining Community Networks

The review of current research and findings sheds light on the ongoing issues that CNs have encountered over the years, notably in terms of sustainability. Despite the different and inventive measures used by CN operators, the literature indicates a consistent theme of a mostly unmet sustainability dilemma [13]. The literature emphasises the complex aspect of sustainability through improving local network operators' abilities to maintain the functionality of community networks through network management, which includes economic, political, and cultural factors [58, 20]. It is clear that differing perspectives on sustainability, both among local network operators and among different stakeholders participating in CNs, add to the complexity of tackling this problem [17].

A critical discussion point emerging from the literature and findings pertains to the evident lack of training among local community members, hindering the development

of essential skills necessary for the maintenance and sustainability of CNs. Despite the diverse and innovative initiatives within CNs, the literature highlights a common challenge: a shortage of adequately skilled individuals within local communities[36]. The sustainable operation of CNs relies heavily on community members actively participating in network design, deployment, and maintenance [120]. However, how can I achieve this when findings in certain CNs show only 1 or 2 active local network operators that rely on external expertise?

In contrast, the prevailing gap in training programs for these individuals impedes the effectiveness and longevity of CNs. The literature emphasises that merely establishing the physical infrastructure is insufficient; the success of CNs is contingent upon local communities possessing the requisite technical expertise to manage and troubleshoot network-related issues[68]. This lack of training not only compromises the sustainability of CNs but also emphasises the need for comprehensive capacity-building programs tailored to the specific contexts of the communities involved [36]. As such, addressing the dearth of training opportunities emerges as a pivotal step towards ensuring the self-sufficiency and longevity of community-driven network initiatives [36, 7].

Participants described the interfaces used, such as the UNMS platform (formerly renamed USIP), the Can-Beams platform, P-f Sense, and MikroTik, demonstrating the breadth of network control tools. However, difficulties exist, particularly when it comes to efficiently navigating these sites. The debate focuses on the difficulties that participants confront, with one participant claiming that the Ubiquity platform is more user-friendly. Importantly, the lack of a network background provides a significant difficulty since businesses with a wide range of key tasks find themselves involved in network development without thorough knowledge, resulting in lengthy setup times.

4.4.2 Strategies and Resources for Enhancing Community Network Sustainability

Finally, another significant discussion point revolves around the guidance and resources employed by local network operators to address these challenges. Participants lean on online resources like YouTube and Google, connecting with industry peers, and engaging with individuals experienced in community wireless networks for troubleshooting. While the Internet proves valuable, participants underscore the unparalleled significance of hands-on experience in problem-solving. Moreover, the need for upskilling through networks is emphasised, highlighting the importance of tutorials, activities, the use of already existing literature, and workshops to enhance the community's self-sufficiency in managing and maintaining their networks

[60, 36].

Recent research efforts have directed attention towards leveraging resource pooling in both time and space through the DTN/ICN hybrid to realise the vision of Global Access to the Internet for All (GAIA) [100]. This approach challenges the conventional idea of continuous Internet connectivity by enabling nodes in challenging networks to interact via methods like time-shifted access. However, significant challenges persist. Our research specifically focuses on the role of resource pooling in wireless networks in the developing world, involving the abstraction of networked resources into a single pool and the development of methods to effectively redistribute the load among its various sections.

The attractiveness of resource pooling lies in its ability to offer durability, high utilisation, and flexibility at a reasonable cost. The research emphasises that "resource pooling," in its various forms, serves as the central unifying element supporting many successful wireless technologies, including white space networking and community networks [100]. This approach holds promise for addressing connectivity challenges and enhancing the efficiency of wireless networks, particularly in resource-constrained environments.

4.5 Chapter 4 Summary

Chapter 4 started with providing an in-depth existing literature, methodology, findings, and discussions related to community networks (CNs) and their management. The literature review discusses barriers to CN creation and scalability, emphasising the lack of awareness, financial challenges, and the need for local technical expertise. It draws from various sources, including Luca Belli's insights on community-driven infrastructure development and Nicola Bidwell's exploration of CNs in Africa within post-neocolonial power dynamics.

This chapter outlined the online interviews conducted in India and South Africa, focusing on understanding current network management practices, participants' backgrounds, experiences with existing interfaces, and challenges faced. The findings section presents insights from interviews with local network operators, discussing the governance, structure, and technology of various CNs, as well as participants' backgrounds, roles, and current network management interfaces.

The challenges identified by participants include difficulties in understanding interface graphs, terminology, and network navigation. The section on ideas for specific features for network management interfaces explores participants' suggestions for improvements, emphasising the importance of user-friendly features, clear access to notifications, and accurate reporting of disconnected devices.

The discussion section delved into key themes emerging from the literature and findings, highlighting the persistent challenge of sustainability and the crucial role of training for local community members. It emphasises the need for comprehensive capacity-building programs tailored to community contexts. The chapter concludes with a summary of challenges identified from the interviews and an overview of participants' ideas for specific features and tools to enhance network management interfaces.

Overall, Chapter 4 shares the findings from interviews. The following chapter shares more findings and discussions from co-design workshops.

Chapter 5

Findings: Network Management Community Based Co-Design

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Some initial findings from chapter 4,5 and 6 were published and presented at AFRICHI 2023, COMPASS 2023 and in the CoRLN report [60, 36].

5.1 Adapting Network Solutions to Community Realities: Insights from Studies on Home Networking Challenges

In Chetty’s studies on home networking, the focus is on the challenges arising from the adoption of network solutions originally designed for work environments within the domestic sphere [49]. The study highlights the mismatch between current network solutions and the unique demands of household settings, where multiple devices coexist [49, 13]. The observational research conducted in the United Kingdom and the United States highlights two key elements crucial for successful home networking: the technical tasks associated with establishing and sustaining a home network, and the collaborative and socially organized activities within the household that are facilitated by the network [49]. This research presents the need for network solutions that align with the specific requirements and social dynamics of households, recognising the dual nature of technical and collaborative work in the context of home networking [60].

Moreover, the discussion focuses on the challenges associated with network management in home environments and introduces the idea of “Eden” which refers to an interactive home network management system specifically created for end users [25]. As home users increasingly encounter complex network management tasks, existing tools developed for enterprise networks prove too complex and unsuitable for household technical peculiarities. Eden addresses these challenges by offering an intuitive, direct manipulation interface for common network management tasks, supported by a simplified conceptual model [25]. The system introduces an innovative home network router designed to seamlessly replace users’ existing routers. It not only enhances the overall user experience in networking but also contributes to a better comprehension of fundamental networking concepts. This investigation emphasises the significance of creating user-friendly solutions tailored to the specific requirements of home network users, bridging the divide between advanced network management tools and the intricacies of domestic networking. In contrast to recent efforts on the Stix network management platform, which focuses on overseeing emerging large-scale broadband wireless access (BWA) networks for bigger communities and organisations, their system is crafted to simplify the management of such networks for community deployments and wireless Internet service providers. This approach ensures that the network management infrastructure remains both scalable and flexible [15, 61].

5.2 UCD: Co-Design Methods and Cultural Preferences in India and South Africa

During the co-design workshops we provided the participants with designing and sketching materials. Participants from Ocean View used the materials to come up with designs of their own using some features from the existing interfaces that they use. However participants from India did not use the material thoroughly to produce new sketches or posters. They preferred to use sticky notes onto the screen. By pasting how they would like that feature to be. Also they wanted to talk more about network management and how they experience it, they also preferred to talk and discuss the features that they desire to see on network management platforms. This can be an issue of co-design readiness however, the discussion were really

Participants in Ocean View were provided with designing and sketching materials during the co-design workshops. They used these materials to generate new designs, incorporating features from existing interfaces they were familiar with. In contrast, participants from Janastu in India opted for a different approach. They used sticky notes to express their preferences directly onto the screen, facilitating discussions about their experiences with network management. This divergence in methods highlights the cultural and contextual differences in co-design preferences. Moreover, in India, the workshops focused on two existing platforms, Libre Mesh and Ubiquity. Participants were encouraged to share their challenges with the current network management interfaces and articulate the features they desired. The discussions led to the creation of prototypes and sketches, with reference to screenshots from UISP and P-fSense interfaces. This approach allowed participants to express their needs and desires for network management features, contributing to a more user-centered design.

Furthermore, participants in South Africa, particularly with Inethi CWN, began by acknowledging their lack of experience with the prevalent network management interfaces. A video tutorial of the UISP platform was presented to familiarize participants with its features. The initial phase aimed at identifying challenges faced by users, such as connectivity issues, signal strengths, and the need for improved user insights. This stage laid the groundwork for addressing specific pain points in the redesign process. In addition, the second workshop activity involved distributing larger posters labeled as the "new interface phase," along with screenshots of UISP interfaces, sticker pads, marker pens, and color paper materials. Participants were organized into groups, and each group collaborated on redesigning specific aspects of the network management interface. The redesign process took into account the challenges presented by participants, fostering a collaborative and iterative approach to improving the interface.

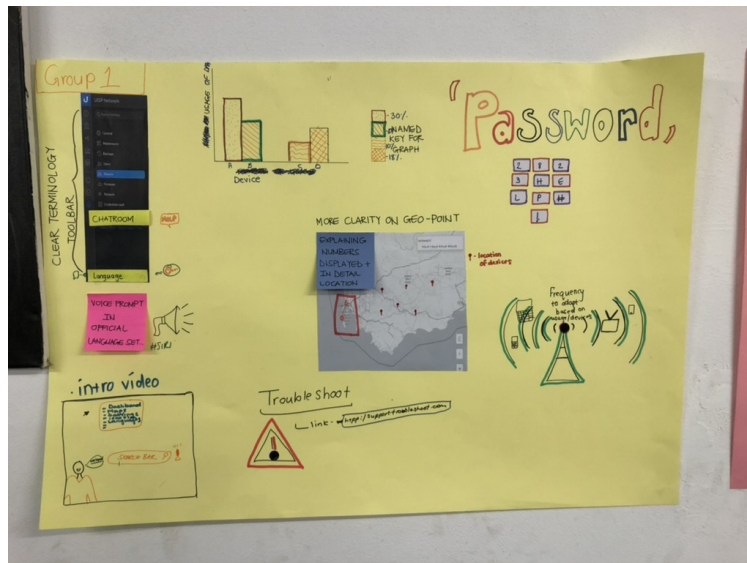


Figure 5.1: Prototype 1 with the presentation from Team 1

The emphasis on group collaboration allowed for diverse perspectives to be considered, contributing to a more comprehensive understanding of user needs. The systemic analysis involved a combination of co-design methods, including sketching, brainstorming with sticky notes, video tutorials, and group discussions. The iterative nature of the workshops facilitated ongoing refinement and improvement of interface designs based on user feedback and collaborative ideation.

5.3 Co-Designed Prototypes

Prototype 1 from Team 1 - The team focused more on the modifications and improvements made to the user interface, particularly for a network management dashboard. The objective was to enhance the clarity, usability, and accessibility of the system for all users. It's evident that the initial version of the program lacked clarity in terms of how the dashboard functions. Thus, changes were introduced to make it more user-friendly and comprehensible. Changes were made to transform the data presentation from a complex graph to a more straightforward line graph. This was complemented by color additions to aid users in quickly identifying increases or decreases in the data. In the case of the map feature, a specific focus was to simplify the zoom function by adding a recognisable magnifying glass icon for easy navigation, particularly for less tech-savvy users. An essential update was the modification of terminology. The team recognised that using terms that were unfamiliar or ambiguous could be a significant barrier to user comprehension. For instance, changing

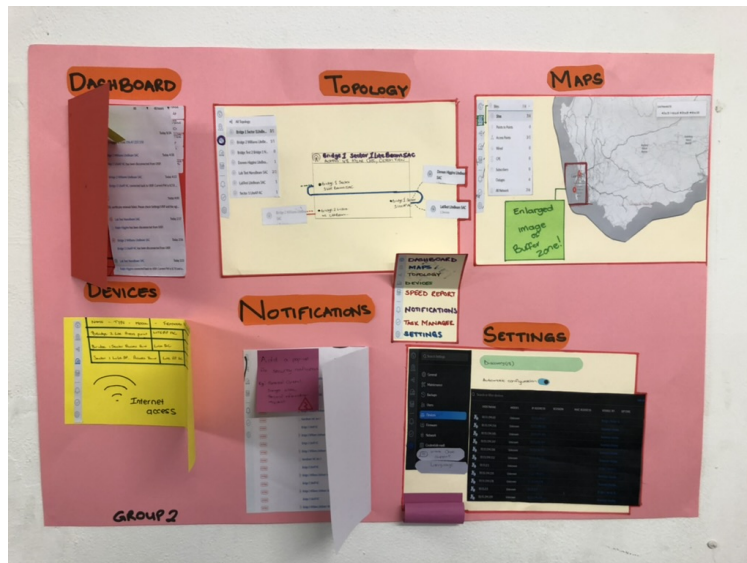


Figure 5.2: Prototype 2 with ideas and solutions were produced by Team 2

”link potential” to ”connection chance” in the legend aimed to provide a clearer understanding for users. Additionally, the presentation made it clear that interpreting the data required an explanation. For instance, an increase in the graph did not necessarily signify an improvement in the signal strength, emphasising the need for clear and accurate interpretation of the data presented on the interface. The presentation ended with an overview of new features added to different sections, like ”data usage” and ”security features” under the dashboard, as well as the inclusion of language settings and online chat under the settings section. These additions were aimed at providing users with additional functionalities and making the platform more inclusive and user-centred.

Prototype 2 produced by Team 2 - Let’s begin with appearances. Simplifying the interface was considered, particularly the graph, suggesting a shift to a bar graph with a less visible key representing specific colors. An example scenario discussed involved providing voice prompts for assistance to guide someone, like a grandmother at home, in troubleshooting network issues while the user is away. Another observation was the absence of a support feature or a chat portal on the interface. It was proposed that if an issue persisted despite changing the IP address, having access to a support chat or a contact number for assistance would be beneficial. To make the system more noticeable and engaging, it was suggested to enhance the interface’s visual appeal with more vibrant colours and graphics. Emphasising the importance of accessibility, the proposal included incorporating brief introductory tutorial videos to explain the system’s functionalities and advantages, encouraging

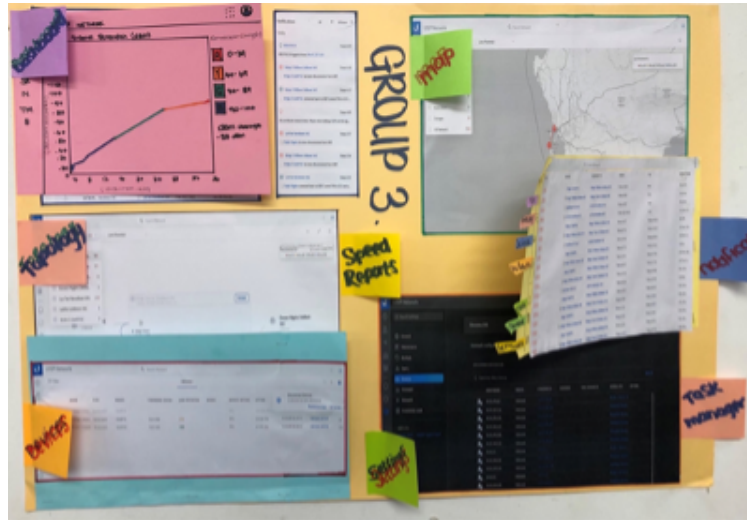


Figure 5.3: Prototype 3 with initial presentation from team 3

users to independently manage tasks rather than waiting for external assistance. To address the unfamiliar terminologies displayed on the interface, the suggestion was to adjust the frequency of these terms based on their usage. It was proposed that as more people use the system, the frequency of these terms should adapt accordingly. Regarding security, the recommendation included the implementation of additional safety measures, such as one-time PINs, confirmation messages, calls, or emails to verify sensitive activities performed on the system. This was aimed at preventing data breaches or unauthorised modifications, particularly those relevant to safeguarding personal information. The interface's improvement involved suggesting a manual toolbar with feature icons accompanied by their names for better user understanding. Additionally, the complexity of passwords was discussed, seeking a balance between security and ease of use, especially for elderly users, where simplicity without compromising security was considered essential.

Prototype 3 produced by Team 3- In our initial presentation, I highlighted the challenge of not knowing the names of icons. The suggestion was a clear terminology toolbar where each icon's name is clearly displayed, enhancing user understanding. Language options were also emphasised, proposing a feature where users could select from 12 official languages, making the interface accessible to a wider range of users without having language-specific versions. The necessity of a chat room was underscored to aid users who face difficulties. An automated response system for frequently asked questions was suggested, where users could type "help" and receive assistance from an AI-powered chatbot. Voice prompts aligned with the selected language were another feature proposed, aiming to cater to diverse language preferences

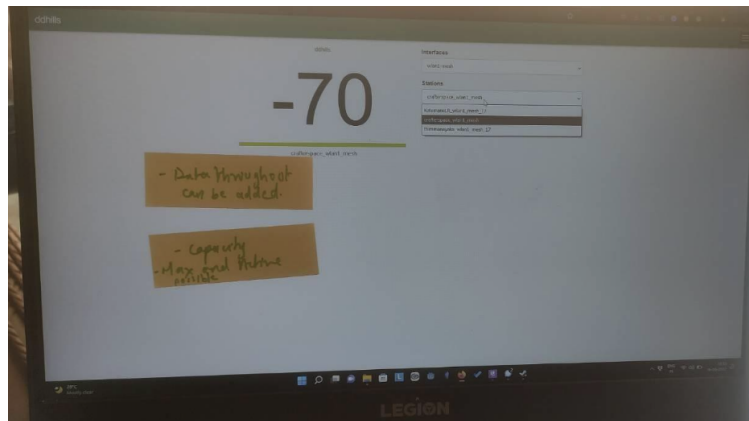


Figure 5.4: Prototype 4 with ideas and solutions produced by Janastu team

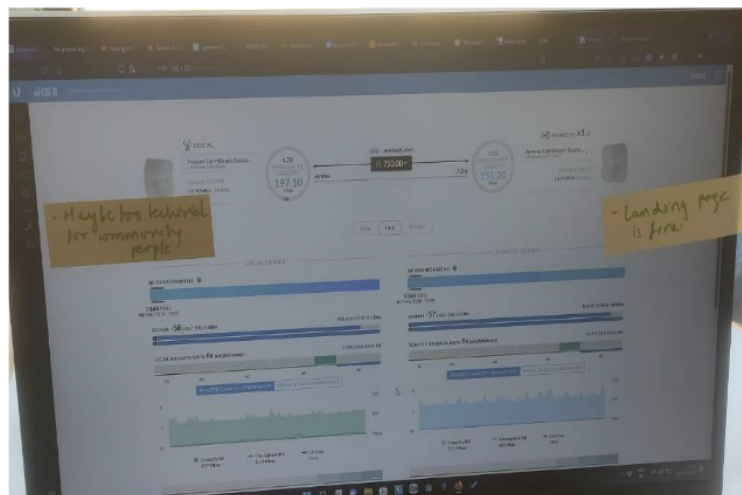


Figure 5.5: Prototype 5 with ideas and solutions produced by Janastu team

among users. Addressing unfamiliar terminologies, the proposal included a short introductory video to familiarise users with the interface and its functionalities. To improve graph comprehension, a shift to a bar graph was suggested, simplifying the representation of device usage. Additionally, using simpler terms like "location pin" instead of complex words to denote device location was recommended. To enhance the understanding of displayed numbers and details, the suggestion was to provide specific information, such as an address and the percentage of data usage. Adapting frequency based on usage and the number of devices was recommended to ensure optimal performance. Moreover, the importance of a vibrant and engaging visual presentation was emphasised to enhance the user experience, an aspect perceived as lacking in the original interface.

5.3.1 Onsite Solutions: Understanding Diverse Approaches to Network Failures

”I first need to fix the network, and someone must come forward from the collective and take the responsibility to fix things within the network. Well, it was a slow process, and it was mostly human interaction and knowledge transfer from the team here.(I/P1)”

This study also found that local network operators manage and understand network management differently. One participant from VNET, Khayelitsha, said she does not use any software interface or network management tool to manage the network. However, she physically manages the network by being onsite, physically troubleshooting by rebooting the network devices or replacing cables or networking devices that she suspects are faulty. This practice means that the local network operators always need to be onsite to detect and solve the network faults as they do not have access to remote network management tools. She also indicated that the only tool she uses is a network speed tester that is available on Google. After she physically manages the network failure error, she connects to the network and tests the speed with the speed tester. Participants from Soweto Wireless User Group ¹ community network also shared their current network management practices; they have technical experts maintaining the network, and they are now familiar with the Ubiquiti network management interface. However, they face challenges with using the MicroTik interface. They said it was challenging to manage and monitor the network at the beginning using the ubiquity interface. However, they illustrated that it gets better with experience, as the local network operator I interviewed has been managing the Soweto Wireless network since 2010. They also mentioned that the other main challenge they experienced was transmitting TP-Link to Ubiquity and the existing WISP. The difficulty was setting up equipment and maintaining the network by ensuring that the network was up and running, troubleshooting the network failures and monitoring the users and the networking devices on the interface.

5.3.2 Challenges and Insights from Design Workshops with Inethi and Janastu

During the co-design prototyping workshops in Ocean View South Africa, the participants were community wireless network users, and only two participants that attended the workshops were part of the interviews. Participants interacted with the community network, at the school or home, through the community’s hotspots. However, I found that community wireless network users need to be exposed to the

¹<https://www.sowug.org.za/>

existing network management tools. For this reason, they define network management as taking care of the hotspots within the community by rebooting the devices when the network fails or calling the local network operators to report the network failures, and they attend to them. To them, network management is more physical on the site rather than using a network management tool to monitor the users and network devices. It is interesting to note that our participants from Ocean View have never used any network management tools. In contrast, our participants from Devrayandurga, Janastu are involved in the day-to-day network management of their community network.

I discovered some of the challenges Ocean View participants faced when using the Ubiquity interface. In their workshops groups, participants discussed that the terminology used on the interface is not suitable for them as they were unfamiliar with the meaning of most of the terms used. Given that it was the participants' first time using and viewing a network management platform, I also found that they had difficulties locating different aspects of the interface. One participant said that it is not obvious what the icons are for once you click on each of them. I also observed this as the participants constantly asked us where I found the hotspots or connected devices. The participants also outlined that tracking network usage is not visible on the interface and that the graphs on the interface are hard to interpret. Participants also expressed that the interface needs to pop out with color.

"It is not obvious what the icons are for once you click on each of them.South Africa,Participant3(SA/P3)"

Furthermore, in the second co-design workshop with three local network operators from Focus, I received more insights from participants with better experience using network management interfaces. Participants indicated that they prefer to use the Radius Desk open-source software to manage the network over the UISP. However, they are also challenged by the migration of the network to the Radius Desk interface. They also attended the school of community networks in South Africa that the APC organized. Given that they were just exposed to community networks at a broader level by interacting with experts and local network operators from other community networks, they shared how difficult it is to install and use the network management interfaces.

"I also said the system to stand out more, so it was not colourful or popping. When I watch YouTube videos or any social media, Instagram, one thing that catches our attention is graphics and colour, so I thought that would be worth following later.(SA/G2)"

"Just like the terminologies, a lot of the terms that were on the interface display, I do not know, making it hard for us to understand network

management. As I said, I do not get some terminologies such as dBm, spectrum, topology, API tokens, Gateway, Network SLA Score, South Africa, Group1(SA/G1)”

I found some of the challenges from the design workshop with Janastu. Participants needed help capturing many network management concepts, such as viewing all the connected users and logs. They said they need to capture more things at the moment of the network management, and they want to view things like how many users are connected signal strengths. They also expressed that they need access to users connected to the network or logs and help to capture this, as they need to know if they should have a raspberry pi (small single-board computer) at every access point or a centralized server. I also found that our participants use individual access point captive portals to manage their mesh network and have challenges accessing them with their phones.

I also found that power issues such as power outages and low battery voltage interfere with network management. Despite the power issues, harsh weather conditions change the alignment of devices that often turn the network down. Harsh weather conditions become a challenge because when the network is down, it is hard for the local network managers to be aware when they are out of town. Local network operators have no remote access to the access point captive portal when they are on site.

”I think the power point that was brought up, power is an active component of this network, and I do not think there is an active management for power at each node that captures power-related data. I think this is ignored by most people or community wireless networks mostly.(I/P2)”

5.3.3 Participants Ideas for Enhancing Network Management Interfaces

Some ideas are specific to local network needs and settings of our community network sites. Two participants from Janastu shared their ideas regarding building a network monitoring tool and some of the tools they are currently using. They had an idea to create a network monitoring tool that pings device to device. They thought of this idea because of the current setup at the Janastu Community Owned Wireless (COW) mesh farm. The farm WiFi connects more firmly as you move around the farm, and the further you are from the hotspots, the weaker your connection. They outlined that when they are debugging a router that does not have an Internet connection, they use a third-party tool called WiFi analyzer by connecting it to the device.

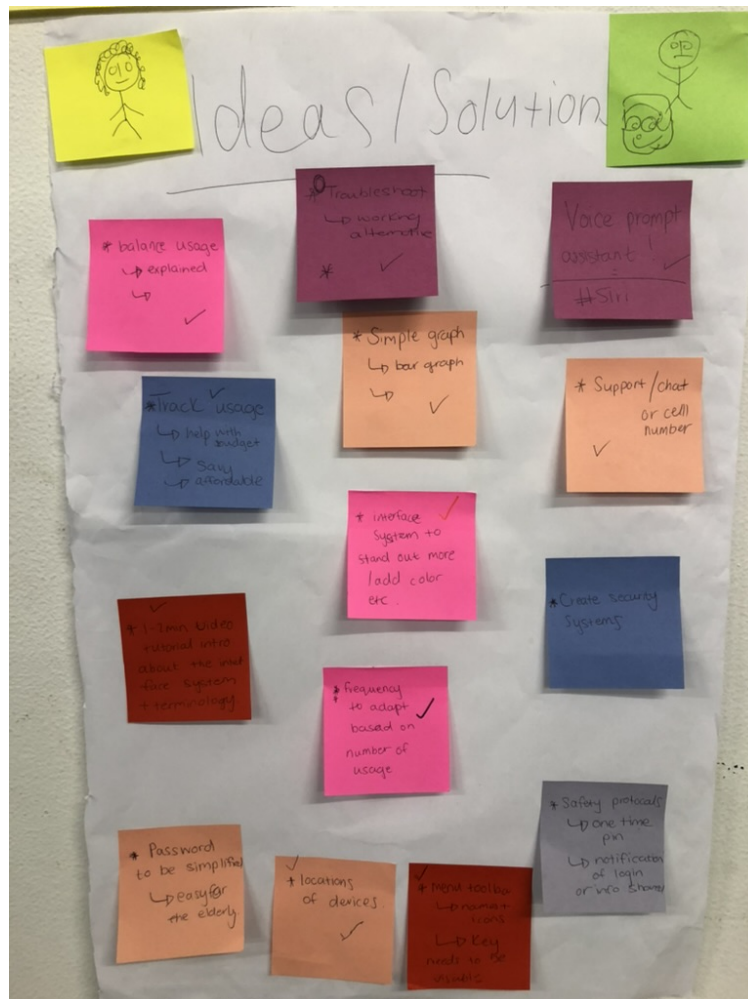


Figure 5.6: Shows some of the input on the new ideas from participants during the co design workshops.

(I/P1) ”So when I were trying to debug, say, some router does not have an Internet that time I used third party tool called WiFi analyzer. The WiFi analyzer is used by connecting it to the device, and then there was all the other process; that is when I got the idea to build a networking tool which says simple things such as if this router is getting Internet or not. I build it in a shell script.(I/P1) ”

”But something interesting happened a month ago. I thought, why not build a network monitoring tool? It is not built and ready to use yet. What it does is, it does node to node ping test with a pi setup, ping test work best from device to device rather than router to router or power

beam”.

During co-design workshops, participants explored network management practices and identified difficulties in the current system. They also proposed creative solutions and co-designed prototypes based on their experiences and needs, which produced important insights. The group talks were collaborative in character, which enabled a rich interchange of ideas that resulted in a thorough set of recommendations intended to improve the system’s general functioning and user experience.

- **Simplifying Terminology and Enhancing Visibility:** Participants had difficulty comprehending the technical words used in the interface. They suggested adding plain language or offering a key that clarifies word meanings as solutions to this problem. Participants acknowledged the significance of visual cues and proposed displaying names next to icons to improve user navigation and guarantee functionality clarity.
- **Introducing Tutorial Videos and Troubleshooting Corner:** The group proposed the creation of a one- to two-minute introduction video tutorial to give users a brief rundown of the system’s functionality, taking into account the diversity of learning preferences. Furthermore, they suggested creating a troubleshooting section with a chatbot to provide automated support for typical problems, highlighting the significance of easily accessible support resources.
- **Improving Device Visibility and Interface Aesthetics:** Enhancing the user experience was a focal point, leading to recommendations such as making devices easily locatable under their respective icons. The group also emphasised the significance of visual appeal by suggesting the addition of vibrant colours throughout the interface and maintaining visible keys for improved user-friendliness.
- **Dashboard Graph Simplification:** Recognising the need for a more straightforward representation of data, participants proposed switching from a data graph to a bar graph with a visible key. This adjustment aimed to simplify data interpretation, ensuring accessibility for users with varying levels of technical expertise.
- **Incorporating Support Features:** Participants identified the absence of a support or chat portal in the existing interface and recommended adding a support chat or contact number. This feature aims to provide users with immediate assistance in case of issues or uncertainties, strengthening the overall support infrastructure.
- **Language Customisation and Accessibility Features:** To accommodate linguistic diversity, the group proposed the inclusion of a language input option and

an online chat within the settings. This aligns with the goal of making the platform more inclusive and accessible to users who prefer interaction in their native languages.

- **Dashboard and Notification System Enhancements:** Several modifications were proposed for the dashboard and notification system, including changes to the graph presentation, clarity in icons, and the addition of a tool bar for better identification.
- **Implementation of Recommendations:** To address these findings and recommendations, the group implemented changes to the system. These changes included transforming the graph into a line graph with added colour for clarity, incorporating a pop-up for security features in notifications, and introducing a tool bar with names for enhanced identification.

In a nutshell, the workshop findings and proposed solutions reflect a collective effort to enhance the usability and effectiveness of the network management interface. These recommendations serve as valuable insights for future improvements, emphasising the importance of user-centred design, accessibility, and continuous support in the evolution of network management systems. The context that the participants' real-world scenarios and discussions provided deepens the significance and applicability of these findings in addressing practical challenges in network management.

Table 5.1: Provides an overview of the network management platforms used by CWNs from this research

Name of the Platform	Description	Features
UISP (Ubiquiti Network Management System)	Description: UISP is a network management system developed by Ubiquiti Networks. It provides tools for managing and monitoring Ubiquiti devices and networks.	Features: UISP includes features for device discovery, configuration management, monitoring, reporting, and troubleshooting.

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Table 5.1 – Continued from previous page

Name of the Platform	Description	Features
MicroTik	Description: "MikroTik." MikroTik is a Latvian company that produces network equipment, including routers and wireless solutions. Products: MikroTik offers a range of hardware and software products, including RouterOS, a Linux-based operating system for routers, and various router models.	Features: configurations, traffic management monitoring and logging user authentication
RadiusDesk	Description: RadiusDesk is an open-source web-based interface for managing RADIUS (Remote Authentication Dial-In User Service) servers. RADIUS is commonly used for centralising authentication, authorization, and accounting (AAA) for network access.	Features: RadiusDesk typically includes features for user management, billing, and configuration of RADIUS servers.
Captive Portal	Description: A captive portal is a web page that users are required to view and interact with before being granted access to a network or the Internet. It is commonly used in public Wi-Fi hotspots, hotels, and other locations where authentication or term acceptance is needed before Internet access is provided.	Functionality: Captive portals often include authentication methods and terms of service acceptance and may provide a means for users to enter credentials or agree to specific terms before gaining network access.

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Table 5.1 – Continued from previous page

Name of the Platform	Description	Features
pfSense	Description: pfSense is an open-source firewall and router software distribution based on FreeBSD. It is designed to be used as a perimeter firewall, router, and more. pfSense is known for its reliability, versatility, and extensive feature set.	Features: <ul style="list-style-type: none"> • Firewall Capabilities: Stateful packet filtering, packet inspection, and complex rule sets. • VPN Support: IPsec and OpenVPN for secure remote access and site-to-site connectivity. • Traffic Shaping: Bandwidth management with QoS configurations. • Web-based GUI: User-friendly configuration and monitoring. • Proxy and Caching: Support for caching frequently accessed content. • High Availability: Failover and redundancy in critical network environments.

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Table 5.1 – Continued from previous page

Name of the Platform	Description	Features
LibreRouter	Description: LibreRouter is a community-driven open hardware router project designed to provide affordable and accessible networking solutions. It focuses on creating hardware that can be used to build community networks, especially in areas with limited Internet infrastructure.	Features: <ul style="list-style-type: none"> • Open Hardware Design: Inspect, modify, and share the router’s design freely. • Mesh Networking Capabilities: Support for wireless mesh networking. • Community-Driven Development: Involvement of the community in development. • Affordability: Cost-effective for community networks and rural areas. • Scalability: Suitable for various community sizes and layouts.
Libremesh	Description: Libremesh is an open-source mesh networking firmware that aims to create a self-configuring and self-healing wireless mesh network. It is designed to be easy to deploy and manage in community networks.	Features: <ul style="list-style-type: none"> • Self-configuring Mesh Networks: Automated setup and configuration. • Node Auto-discovery: Automatic detection and integration of new nodes. • Community Networks: Well-suited for collaborative community networks. • Customizable: Configuration based on specific requirements. • Monitoring and Management: Tools for monitoring network health and performance.

5.4 Discussions

Chetty’s studies and other research on designing interfaces for network management (NM) stress the difficulties of using network solutions that were originally created for work settings in home settings [49, 13]. The mismatch between existing network solutions and the specific demands of household environments, where both technical and collaborative work intersect, emphasises the need for tailored solutions that consider the unique requirements and social dynamics of home networking [60]. This literature also delves into the challenges associated with network management in home environments, introducing the ”Eden” system as a user-friendly solution to bridge the gap between advanced network management tools and the complexities of domestic networking [25].

In response to these insights, the prototypes presented by Team 1 and Team 2 provide practical illustrations of efforts to enhance the user interface and functionality of network management systems. Team 1 focused on refining the clarity, usability, and accessibility of the system, addressing issues such as data presentation, terminology, and the addition of new features to improve the overall user experience [49]. On the other hand, Team 2 proposed visual enhancements, voice prompts, and additional support features to make the interface more engaging, accessible, and user-friendly, catering to a diverse user base, including those less tech-savvy [25]. These prototypes align with the literature’s call for user-centred, tailored solutions in the realm of home network management.

The discussion then further transitions to a detailed examination of challenges faced during the brainstorming and prototyping workshops, shedding light on the diverse approaches to network management in different community contexts. The incorporation of local network needs and settings emerges as a crucial aspect, with participants expressing the need for more physical, on-site network management in certain community wireless networks [15, 61]. Problems that were brought up in these workshops, like unfamiliar terms, finding interface elements, and power problems that affect network management, show how important it is to take into account the specific needs and points of view of local network operators[61, 105]

Furthermore, existing literature leads to contemplation on the importance of interfaces being attuned to the unique needs and configurations of local networks. Lessons drawn from community network initiatives, such as the conceptualization of a network monitoring tool executing device-to-device ping tests, illustrate the significance of customising interfaces to address the distinct requirements and obstacles encountered by local communities [15, 61]. In summary, the literature and prototype discussions highlight the ongoing efforts to design interfaces for network management that are not only technically robust but also considerate of the unique social, tech-

nical, and contextual aspects of home and community networks. This user-centred approach, as demonstrated in the prototypes and community workshops, is crucial for developing effective, inclusive, and accessible network management solutions.

5.5 Chapter 5 Summary

Chapter 5 explored the findings from co-design workshops, focusing on understanding network management practices. The chapter begins with a review of detailed literature on designing interfaces for network management, referencing Chetty's studies and other relevant research. Chetty's work emphasises the challenges arising from applying network solutions designed for work environments to household settings, highlighting the need for user-friendly solutions tailored to the unique demands of home networking.

The chapter then delves into more detailed methods for systemic analysis of network management interfaces, discussing challenges related to complicated interfaces that rely on external knowledge. It presents findings from co-design workshops with local network operators and prospective operators.

The co-design workshops feature prototypes created by Team 1 and Team 2, both aiming to improve the user interface and functionality of network management systems. Team 1 focuses on enhancing clarity, usability, and accessibility, addressing issues such as data presentation and terminology. Team 2 proposes visual enhancements, voice prompts, and additional support features to make the interface more engaging and user-friendly.

The section on findings explores co-designed platforms, presenting insights from prototype presentations. It includes detailed discussions on the modifications made to improve user interfaces, such as changes to data presentation, simplification of terminology, and the addition of new features for inclusion and user-centred design.

Physically troubleshooting and handling network failures are also discussed, revealing that local network operators manage and understand network management differently. Some prefer physical troubleshooting on-site, while others rely on remote network management tools. Challenges expressed during brainstorming and prototyping workshops shed light on the difficulties faced by community wireless network users, emphasising the importance of exposure to existing network management tools.

The chapter concludes with ideas for network management interfaces that are specific to local network needs and settings. Participants share insights from community network sites, including an idea for a network monitoring tool that performs

device-to-device ping tests. The importance of tailoring interfaces to the specific requirements and challenges faced by local communities is emphasised throughout the chapter. The following chapter shares more findings from deployment and evaluations.

Chapter 6

Findings: Network Management Outcomes Based on Deployment

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Some initial findings from this chapter were published and presented at AFRICHI 2023, COMPASS 2023 and in the CoRLN report [60, 36].

6.1 Community-Driven Insights: Case Studies and Workshops Shaping HCI and Networks

The fusion of HCI and networking opens up an interdisciplinary space that combines social, ethical, and technical dimensions. Scholars such as Esther Jang, Phoebe Sengers, and Nic Bidwell contribute significantly to this field, offering insights that provide better understanding of the intersection between technology and human interaction [63, 19, 18, 20]. Esther Jang’s paper *Unravelling the Social Aspects of HCI and Networking* delves into the social dynamics of HCI and networking, examining how users interact with technology in various social contexts [63]. Her research emphasises the need to understand the nuanced ways in which individuals, communities, and societies engage with networked technologies. Jang’s contributions shed light on the human side of networking, exploring issues such as accessibility, usability, and the impact of technology on social structures. Phoebe Sengers contributes to the literature by focusing on the ethical implications of networking technologies. Her work extends beyond technical considerations to explore the broader societal and individual impacts of networked systems. Sengers raises critical questions about the ethical responsibilities of designers and users in the context of HCI and networking, challenging traditional perspectives and prompting a more thoughtful and responsible approach to technology development. Nic Bidwell’s research on bridging the technical aspects of HCI and networking brings a technical lens to the intersection of HCI and networking [19, 20]. By investigating the design and implementation of networked systems, Bidwell contributes valuable insights into the technical challenges and opportunities in creating user-friendly and efficient network interfaces. Her work is essential for understanding the technical requirements that underpin effective human-computer interaction in networked environments.

Relevant workshops and case studies, such as “Situating Network Infrastructure with People, Practices, and Beyond,” have the shared goal of establishing a global community that includes researchers and network infrastructure deployers. The overarching objective is to explore both the design challenges and opportunities inherent in integrating the technical dimensions of networked infrastructures with Human-Computer Interaction (HCI) and the social science of infrastructure [63]. By actively seeking to bridge the gap between technical experts and HCI scholars, these deployment workshops also looked into the experiences of local network operators and researchers involved in designing inclusive and efficient networked technologies. In a parallel study titled “Network Capacity as a Common Pool Resource: Community-Based Congestion Management,” the investigation focuses on congestion control mechanisms within community-owned networks. In these networks, users wield influence over their daily operational decisions [66]. Framing network capacity as a Common Pool Resource (CPR), the research explores various

tools and policies that facilitate communal network management [66]. The findings contribute valuable insights into the transformative potential of community-based approaches capable of reshaping traditional congestion control mechanisms. In a distinct case study titled "The Network Is an Excuse": Hardware Maintenance Supporting Community, the research zeroes in on community-managed WiFi networks in Argentina. Through the lens of actor-network theory, the study scrutinizes the intricate social relations intertwined with maintenance within these networks [46]. The synthesis of these studies collectively highlights the growing importance of community involvement and tailored methodologies in reshaping the landscape of network infrastructure and technology.

The research suggests that networking technologies play a crucial role in shaping collective work practices and intentionally configuring technologies to support collaborative learning. The study advocates for designing not just for repair but for accessible repair experiences that facilitate effective collaborative learning. In conclusion, the literature presented by Jang, Sengers, and Bidwell, as well as the insightful case studies and workshops, collectively contribute to a nuanced understanding of HCI and networking. This multidimensional exploration highlights the need for a holistic approach that considers both the technical complexities and the social implications, paving the way for more inclusive and ethically sound networked technologies [63, 66, 46].

6.2 Lessons from Real-World Networking Deployments

The experiences shared in "Stories from the Field" highlight the endeavours of networking researchers in extending the advantages of Internet access to underserved communities [55]. This extensive reflection spans over a decade, covering deployments in diverse settings, including rural, urban, developed, and developing regions. The valuable lessons and narratives presented in this work serve as a call to action for fellow researchers to contribute their own stories, fostering knowledge exchange within the broader networking research community [55]

An essential lesson derived from real-world networking deployments emphasises the physical nature and purposeful design of networks. The narrative on capacity building emphasises that effective teaching and training in practical networking occur in the field, requiring hands-on experience and an understanding of the physical aspects, such as mounting and cabling. NYC Mesh is an example of a successful training strategy that relies on frequent hands-on installs overseen by knowledgeable installers to foster the ongoing development of volunteer capacity as the network

grows [56].

A notable anecdote from the Indonesian deployment reveals a steady operational phase where hardware repair was conducted locally, showcasing successful instances like hard drive replacement [55]. However, a critical outage emerged, leading to the realisation that the weatherproofing had deteriorated. Surprisingly, the issue wasn't weather-related but stemmed from unexpected factors: the affinity of bugs for radio frequency, the conductive nature of cockroach urine, and the susceptibility of motherboards to short circuits [55].

A compelling account of the deployment in a rural Indonesian village highlights the realisation that deploying novel networking tools necessitated the use of licenced spectrum [55]. Despite facing resistance from the local regulator, who discouraged further discussions, the project persevered, resulting in a system that has sustained operations for more than a decade. The narrative emphasises the influence of spectrum policy on the rural-urban gap, a factor initially beyond the scope of the technology project.

Another study [64] looked at the challenges and processes involved with technology repair in rural, underdeveloped areas without access to normal ICT repair facilities. These communities are geographically far from cities, and the nearest peri-urban settlement, Baler, is several hours away by boat, sometimes made more difficult by poor weather. Unlike other research conducted in more connected rural areas, this study found that the lack of local repair shops contributes to the infrequency of device repairs even while the severe environmental conditions for electronics frequently cause malfunctions [64]. This study emphasised the marginalisation of coastal communities with regard to various forms of public infrastructure, highlighting the difficulties in achieving local repair despite the differences between urban and rural infrastructure. However, in isolated environments, unofficial trust-based repair networks occasionally emerge to patch these gaps. In light of these places' remoteness and the perceived benefits of repair, the article clarifies how trust affects the dynamic creation of repair infrastructure. Building trust networks between repairers, suppliers, clients, other repairers, and certifying or training institutions is essential to allowing resources and expertise to flow throughout the Philippines while also maintaining the marginal status of residents and repairers in the coves [64]. Local communities show how to maintain a robust ecosystem for rural electrical line repair in the face of structural obstacles; this serves as a model for the more general approach of creating training grounds to preserve and grow local communities of repair professionals [64].

6.3 Radius Desk for Community NM

Based on understanding of user requirements obtained through co-design workshops and interviews before I started the deployment phase. I identified high-priority features, such as tracking the geographic distribution of devices or mesh networks, identifying devices experiencing problems, and differentiating between network devices and people.

I investigated a number of open-source network management interfaces, including LibreNMS, Monitorix, and Radius Desk (RADIUSdesk). Even though it needed minor interface tweaks, Radius Desk turned out to be the best option for overseeing community wireless networks (CWNs) after a thorough analysis. This is because one of the local network operators was using it for voucher management portion of network management but not the network devices.

Using Radius Desk for overall network management and gaining a grasp of its functionality especially for users, is essential to comprehending the complexities of Radius Desk. Through Reference IDs in RADIUSdesk, a user can be linked to other entities: realm-id binds the user to a Realm, profile-id links the user to a profile that establishes service parameters, and user-id identifies the owner (Access Provider).

You require an Owner, a Profile, and a Realm in order to create a user in RADIUSdesk. This preparation becomes more crucial when creating users through the API and emphasizes the essential steps in the network management process.

6.4 Hands-on Training with Radius Desk Deployment

The deployment of the Radius Desk within the mesh networking framework was the focus of several talks and activities during the researcher-led NMI Deployment Workshop for Inethi and Janastu CWNs. For this workshop I prepared the following workshop materials including the firmware procedure:

- procedure on Radius Desk Installation
- <https://openwrt.org/toh/ubiquiti/unifiac>,
- <https://downloads.openwrt.org/releases/21.02.3/targets/ramips/mt76x8/>
- <https://openwrt.org/toh/start>
- demo set up devices: 6 Ethernet cables, 2 Ubiquiti AC Mesh, 1 mini switch, and Pf – Sense firewall

These materials provided directions on how to install and connect devices on to the Radius Desk platform in detail. OpenWrt platform flashing firmware instructions were also provided.

Sharing insights from previous interviews and workshops with Janastu and Inethi CWNs helped establish the framework for the deployment plan. The goal of the first half-hour was to acquaint participants with the mesh desk interface by demonstrating various features like installing access points, controlling users, and keeping an eye on gadgets. Participants had the chance to interact during this portion by posing questions.

The following exercises were designed with real-world applications in mind. In Activity 2, participants worked under the facilitators' instructions to set up a Radius Desk and connect devices. This 1-hour training covered the practical application of Radius Desk for network management.

Activity 3 included a demonstration of flashing an access point and connecting it to the Radius Desk interface. It was held from 1 hour. In order to complete the process on their own, participants were urged to participate in group activities.

The final session, which was set for 1 hour, consisted of participant input about their deployment workshop experiences. The participants explored their perspectives on network management with Radius Desk and expressed their thoughts on a range of topics, such as adding devices and clients. The viability and desirability of continuing with Radiusdesk, as well as participants' possible access to the interface, were other topics of discussion.

Throughout the workshop, the plenary sessions offered a forum for group discussions and reflections on the deployment process, guaranteeing thorough comprehension and participation from all participants.

6.5 Deployment Workshop with Janastu

In the network management interface (NMI) deployment workshop with Janastu, our focus was on deploying the Radius Desk networking monitoring interface. The workshop began with the deployment of the Radius Desk interface, a pivotal moment where participants delved into the features designed to enhance network monitoring and management. A key highlight was the participants' positive response to the interface, particularly emphasising its dashboard and network monitoring components.

Dashboard Dynamics: The dashboard feature emerged as a standout element for the network operators involved in the workshop. They expressed a notable appreciation

Table 6.1: Janastu deployment workshops participants

Name	Gender	Role
Participant 1	Male	Janastu Co-founder
Participant 2	Male	Technical Network Operator
Participant 3	Male	Technical Network Operator
Participant 4	Female	Technical Network Operator
Participant 5	Female	Design Input

Table 6.2: Participants of the network management deployment workshop in India with Janastu. The workshop took place on 3rd May 2022 in DDhills.



Figure 6.1: Deployment workshops with Janastu CWN members

for the comprehensive features embedded in the interface. This included a keen interest in the network monitoring components, showcasing a desire for a more efficient and centralised method of overseeing their network infrastructure.

Table 6.3: Inethi deployment workshop participants

Name	Gender	Role
Participant 1	Female	OV Community Member
Participant 2	Female	OV Community Member
Participant 3	Male	OV Community Member
Participant 4	Female	OV Community Member
Participant 5	Male	OV Community Member

Table 6.4: Participants of the network management deployment workshop in South Africa with Inethi. The workshop took place on 12th May 2022 in Ocean View

Transitioning from Libre Mesh: During discussions, participants revealed that they were accustomed to using Libre Mesh for network management and monitoring. However, they faced the challenge of having to log in to each router’s captive portal individually to assess the network’s status. The introduction of Radius Desk presented a promising alternative, offering the prospect of monitoring all devices within a network through a unified and user-friendly interface.

Seeking a Unified Network Monitoring Platform: A recurrent theme in the participants’ feedback was the eagerness to transition to a platform like Radius Desk. The prospect of having a centralised interface capable of monitoring all access points on a network was particularly appealing. This desire echoed a longstanding quest for a more streamlined and efficient solution, replacing the need for manual logins on individual routers.

The workshop not only facilitated the deployment of the Radius Desk interface but also served as a forum for valuable insights into the preferences and challenges faced by network operators. The expressed enthusiasm for transitioning to a unified network monitoring platform underscored the potential impact of deploying advanced interfaces on enhancing the efficiency of network management practices.

6.6 Deployment workshop with Inethi

During the Inethi deployment session, I had community members and prospective network operators as participants, not active local network operators. They are a subset of the network management design workshop that happened in March.

Inethi network operators were given an overview of the deployment procedure, and the early results from the previous NMI deployment workshop in India were shared to set the stage for the session.

To begin the practical section, participants were given a general introduction to the Radius Desk NM platform and guided through its features as a group. After that, the participants were split into two groups, each of which used a different desktop to visit the `inethi.net` Radius Desk URL. Essential network management topics were discussed, including adding users and access points and keeping an eye on linked devices.

Live Demo: Radius Desk Connection with Access Points In the workshop’s second section, a live demonstration of connecting access points to the Radius Desk was given. To enable Radius Desk to recognise and control the connected devices, a crucial step in this procedure was flashing the devices with an OpenWRT firmware that was compatible with them. Even though some participants found firmware and flashing complicated, there was a noticeable buzz around the live demo—especially when it came to setting up a one-node network in the classroom.

Feedback from Participants: Following the demonstration, participants gave insightful comments. Most people found the technical features fascinating, especially the Radius Desk and the wireless network demonstration. Participant 1 was eager to learn more, pointing out that even though flashing seemed dangerous, prolonged exposure would improve comprehension. Participant 2 expressed doubts about instant use, finding the setup and flashing to be complex. Participant 3 emphasised the need for more research, especially in firmware handling, while acknowledging that they understand the Radius Desk’s platform network administration.

After the workshop, attendees were given access to the Radius Desk NM platform. Interestingly, two participants using phones and three using laptops indicated that they intended to use the platform on their own. This suggests that the community may be moving towards more accessible and inclusive network management options.

6.7 Evaluation and Asynchronous Feedback

As mentioned before in chapter 3, three weeks after the deployment workshops, the participants of the deployment workshops were requested to provide feedback and evaluations were conducted. I employed a multifaceted evaluation strategy, incorporating walk-through demonstrations, observations, take-home studies, and open-ended interviews, to evaluate the RADIUSDesk Network Management (NM) platform.

In the walkthrough demonstrations, I showed the prospective users, who were the participants, the RADIUSDesk platform while still having complete control over the interaction. Unlike cognitive walkthroughs, this method looks at participants’ overall perceptions rather than requiring them to actively participate in order to identify



Figure 6.2: Deployment workshops with OV community members

usability problems. I explained the platform’s operation during these demos, providing examples and pointing out any possible drawbacks.

For the use of observation, in order to ascertain how users interacted with the RADIUS Desk NM platform to carry out a specific task, including closed activities that had predetermined answers and open tasks that required participants to come up with and carry out their own solutions, direct observation was used. In addition, take-Home Studies at the end of the deployment workshops, when each participant has logged in to RADIUS Desk and they have tried using the NM platform outside school lab settings while using the CWN at their homes.

Three weeks after the deployment workshops, I carried out open-ended interviews to learn about participants’ experiences and difficulties completing tasks using the NM platform. These interviews were only in-person with the Janastu team in India because I was in India during the time of these interviews for analysis purposes. However, for participants from Ocean View, the interviews were conducted online, and they sent me written feedback. These interviews began with pre-written questions but allowed for flexibility and in-depth investigation and gave important insights on the methods, achievements, and potential weak points of the platform used by users. Interviews also helped to clarify how users saw particular RADIUS desk features, which put other usage data in context. The feedback was documented by incorporating quotes from participants to enhance the findings and keep the qualitative element of this research.

6.8 Participants Feedback on the Deployment with Inethi

During the workshop, participants encountered technical challenges in understanding the process of connecting Access Points to Radius Desk, particularly the necessity of flashing devices with compatible OpenWRT firmware. However, they worked their way through the complexities of connecting access points to the Radius Desk. One noteworthy aspect was that in order for Radiusdesk to detect connected active devices, devices had to be flashed with OpenWRT firmware. Even though there was some uncertainty during this procedure, the participants' joy was evident, especially when they saw how a 1-node network was set up in the classroom for demonstration.

User comments on Radius Desk revealed a wide variety of responses. Despite the technical complications, one participant indicated cautious interest, recognising opportunities for more in-depth learning. Another participant, on the other hand, had doubts about independent usage and thought the setup process was complicated. However, a third member praised Radius Desk's extensive network administration features, highlighting its user and hotspot identification systems. In Addition, after the implementation, the participants conducted a comparison study of Radius Desk and UISP. Radius Desk was cited as having several notable benefits, including better voucher administration, better device visualisation, and easier device connectivity. Feedback from users prompted proposals for interface enhancements, including the addition of a menu-equipped home button and the division of devices into users and hotspots for better navigation.

Participants showed a general preference for Radius Desk over UISP, despite early difficulties. Perceived benefits in device visualisation, voucher administration, and overall user-friendliness led to this selection. As the most complete and preferred method of administering the implemented network that satisfies user requirements and expectations, Radius Desk has come to light. Moreover, a legitimate worry was voiced by a participant about the restricted firmware support available for certain devices, specifically light and nanobeams. This led to thinking about several approaches, such as adding a Unifi firewall to deal with compatibility problems. For the deployment workshops to continue to be successful, it became clear that a wider range of devices needed to be seamlessly integrated into the network. Furthermore, the insights gained from the participant's experiences and views throughout the workshop are significant and warrant further consideration. They set the stage for further improvements, amplifications, and deliberations in the deployment workshops by stressing the significance of resolving technical difficulties, enhancing user interfaces, and guaranteeing compatibility with a wide range of network devices. These findings aid in the further development and improvement of community net-

work deployment approaches.

Participant	Affiliation	Gender
1	Janastu	Female
2	Janastu	Male
3	Janastu	Male
4	Janastu	Male
5	Janastu	Male

Table 6.5: NMI co-design workshop with participants from Janastu

6.9 Participants Feedback on the Deployment with Janastu

During the deployment workshop in India with participants from Janastu, the focus was on installing and connecting devices to explore the features of Radius Desk on PCs. Participants were given the opportunity to familiarise themselves with the interface by engaging in hands-on activities. Following the installation, discussions were initiated to gather feedback on the participants' impressions of Radius Desk and its potential integration within their network management practices. Furthermore, participants shared insights into the current challenges faced by their team, particularly in connecting the router to the Radius Desk. While acknowledging the difficulties in navigating the documentation, there was a keen interest in exploring the usability aspects once the setup process became more straightforward. The participant highlighted the desire for features related to viewing devices online and points of failure with various configurations, expressing optimism about Radius Desk's potential as a network management system. Despite considering a centralised server, the preference for a distributed management system was noted, contingent on the ease of setup and instructions.

Moreover, participants expressed a positive outlook, considering the Radius Desk to be more advanced than what they had been seeking. Acknowledging its status as an open-source and under-development tool, there was enthusiasm to dive into its technical aspects and address challenges as they arise. The participant also discussed the possibility of replacing their switch with a single compatible router that aligns with OpenWRT and Radius Desk. Compatibility with AC mesh devices was emphasised, as their current tp-link router models posed compatibility issues. In addition, participants expressed optimism about the features observed in the Radius Desk dashboard, deeming them ideal for their needs. The participant suggested the potential of leveraging Radius Desk's open-source nature to build a customised

user interface (UI). The participant's vision for customising the tool to meet their unique needs was in line with the idea of exploring Radius Desk's development and extension, which emphasised the flexibility Radius Desk's open-source nature offers.

In a nutshell, the results from the Janastu deployment workshop in India indicate a range of perspectives among participants. Despite initial challenges, there is a collective willingness to explore and integrate Radius Desk into their network management practices, with a focus on usability, advanced features, and the potential for customisation to suit their specific needs. The feedback and considerations provided by the participants offer valuable insights for further refinement and adaptation of Radius Desk within the context of Janastu's network management needs.

6.10 A Discussion on HCI Principles in Networking: Fostering User-Friendly Interfaces

In the initial stages of the deployment workshops with participants from Janastu, several aspects emerged as particularly effective in facilitating engagement and understanding. One notable success was the hands-on installation of Radius Desk on the computer they use, allowing participants to explore the interface and its features firsthand. This practical approach created an immersive learning experience, enabling participants to familiarise themselves with the tool in a tangible way. Furthermore, the interactive talks, which generated a variety of viewpoints and insights from the participants about the usability and possible integration of Radius Desk into Janastu's network management practices, proved to be beneficial.

The effectiveness of these initial steps highlights the significance of incorporating Human-Computer Interaction (HCI) principles into the broader conversation about networking. HCI focuses on the design and use of computer technology, emphasising the interaction between humans and computers. Bringing HCI into the realm of networking is crucial for several reasons. Firstly, HCI principles contribute to the development of user-friendly interfaces and intuitive designs. In the context of community networks like Janastu's, where participants may not have extensive technical expertise, a well-designed interface can significantly enhance the usability of networking tools. By prioritising user experience, HCI ensures that technology is accessible and understandable, fostering greater participation and engagement among users. Secondly, the integration of HCI principles promotes effective communication between technical experts and end-users. The workshops demonstrated that open discussions about the challenges faced by participants in connecting routers and navigating documentation are vital for identifying usability issues. HCI encourages a user-centred approach, fostering dialogue and collaboration between developers and

end-users to co-create solutions that address real-world challenges.

Furthermore, HCI principles emphasise the importance of considering the socio-cultural context in technology design. In the case of Janastu, understanding the unique needs and preferences of the community members is crucial for tailoring networking solutions to their specific requirements. HCI encourages a holistic approach that considers not only the technical aspects of networking but also the social and cultural factors that influence user interactions with technology. HCI principles advocate for understanding users' varied experiences and preferences, paving the way for tailored solutions that accommodate different skill levels and usage scenarios. The feedback from participants on proposed interface enhancements, such as the addition of a home button and improved device categorization, further emphasises the need for continuous improvement based on user feedback. The expressed concern about limited firmware support for certain devices emphasises the need for a holistic HCI approach that considers not only the technical aspects of networking but also the practical constraints faced by users. HCI principles advocate for inclusion and accessibility, and addressing compatibility issues is vital for ensuring that a wider range of devices can seamlessly integrate into the network.

In summary, the effectiveness of the first phases of the deployment workshops with Janastu participants highlights the significance of bringing HCI concepts into the larger networking conversation. By putting the user experience first, encouraging good communication, and taking socio-cultural factors into account, HCI makes sure that networking solutions are not only technically sound but also inclusive, user-friendly, and sensitive to the demands of a variety of communities. In the end, this strategy helps ensure that community networks are successfully adopted and maintained.

6.11 Chapter 6 Summary

This findings chapter offers a detailed exploration of community networks and the challenges faced by local operators between June 2021 and June 2022. From network management issues to the experiences and backgrounds of operators, we've delved into the intricacies of community wireless networks. The chapter sheds light on hardware diversity, shortages, troubleshooting, and the dynamic interactions during brainstorming sessions. Insights into operator backgrounds, their aspirations for network management tools, and the influence of external expertise provide a comprehensive view. Weather conditions, power cuts, and the importance of training round out the multifaceted landscape of community-driven networks, showcasing the resilience and adaptability of local operators.

Chapter 7

Discussions

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This chapter presents the research findings in conjunction with existing literature, including the importance of incorporating the local knowledge and skills of community operators when designing network management interfaces. This consideration is crucial for ensuring the sustainability of community networks, involving the active participation of local network operators and community members. Preliminary discussions from this chapter were previously published and presented at AFRICHI 2023 and in the CoRLN Report [60, 36].

7.1 Technical Plan and System Implementation Architecture

The findings show that all CWN that participated in this research use a combination of different branded networking equipment. Thus causing them to manage the network with different network management systems based on the network equipment brand. Some of the network equipment that they have in common is Ubiquiti, Libremesh, and Tp Link.

Ubiquiti Networks is a technology company that specialises in the development and manufacturing of networking equipment and solutions. Founded in 2005, Ubiquiti has gained prominence for providing high-performance, cost-effective wireless communication and networking products. The company offers a diverse range of devices, including wireless access points, routers, switches, security cameras, and other networking components. Ubiquiti is well-known for its Unifi product line, which includes a unified management system designed to configure and monitor various networking devices seamlessly. The Unifi system operates through a network controller software that allows users to manage their networks independently of the specific hardware devices. This approach provides flexibility and ease of use for deploying and maintaining network infrastructure. However, after as the network expands there is a need for subscription fees.

In the context of deployment workshops, experimentation involved flashing Ubiquiti AC Mesh and Tp Link routers with OpenWrt firmware to integrate them into the RadiusDesk network management system successfully. However, the process of connecting these devices posed challenges for both participants and the researcher. As discussed earlier, the creation of a user in RADIUSdesk necessitates an owner, a profile, and a realm, introducing complexity to the user setup process. Furthermore, the visibility of connected and unconnected users in the RADIUSdesk interface proved less intuitive. Despite these challenges, it's noteworthy that the RadiusDesk backend demonstrates versatility by accommodating various network devices, including Ubiquiti and Tp Link routers, as long as they are flashed with OpenWrt software. This emphasises the potential for standardised open-source solutions to seamlessly integrate with diverse hardware within CWNs, promoting flexibility and interoperability.

7.2 NMI Web Application Development

Following a comprehensive analysis of network management interface prototypes from the co-design workshops, four key features were identified to serve as guiding principles for the development of the network management interface (NMI) tailored

for local network operators. The primary focus of this research was on front-end development, leveraging ReactJS—a JavaScript library renowned for streamlining the creation of user interfaces [103]. The NMI functions as a plugin operating atop the UNMS (Ubiquiti Network Management System) or RadiusDesk infrastructure, presenting users with an interface designed for enhanced user-friendliness.

The front-end interface, developed with ReactJS, interfaces seamlessly with the UNMS API, facilitating the retrieval of information from the back-end and transmitting it to the NMI web application. This integration proves especially valuable for Community Wireless Networks (CWNs) utilising Ubiquiti devices exclusively. However, for CWNs employing a combination of devices, the NMI communicates with the RadiusDesk, ensuring adaptability across diverse network environments. The utilisation of APIs is an important aspect in contemporary web application development, and the NMI web application aligns with this trend. By accessing data through the UNMS API, the NMI becomes an integral part of the existing services and devices within the network. Specifically, within the UNMS API's device section, a comprehensive list of all connections to access points and Unifi devices can be extracted, providing valuable insights for effective network management.

In essence, the NMI web application serves as an innovative layer that merges with existing network infrastructure, offering local network operators a tool for managing their networks. Through the seamless integration with UNMS or RadiusDesk, it enhances the accessibility and usability of network management interfaces, contributing to a more streamlined and user centred experience for operators working with a variety of networking devices in a Community Wireless Network setting.

On the development of the NMI I have focused on the following pages:

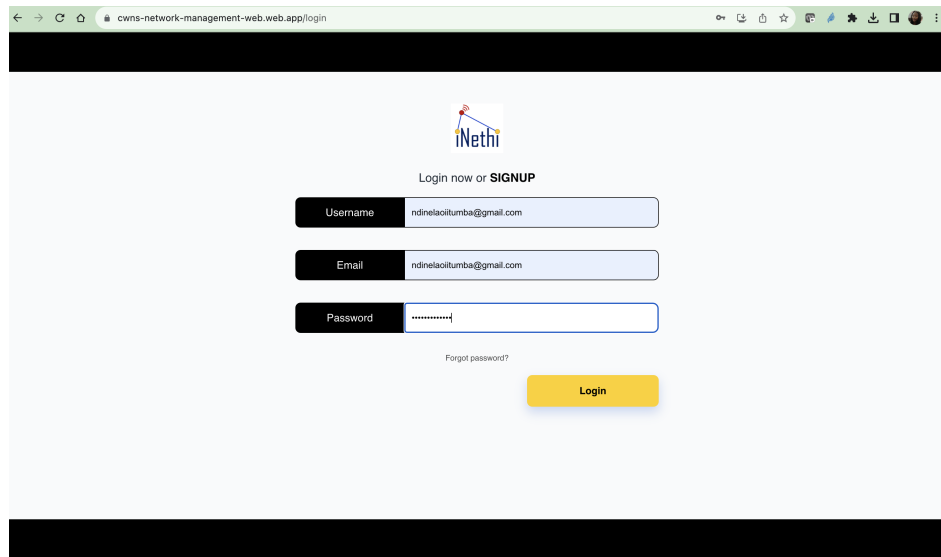


Figure 7.1: The login page of the new NMI

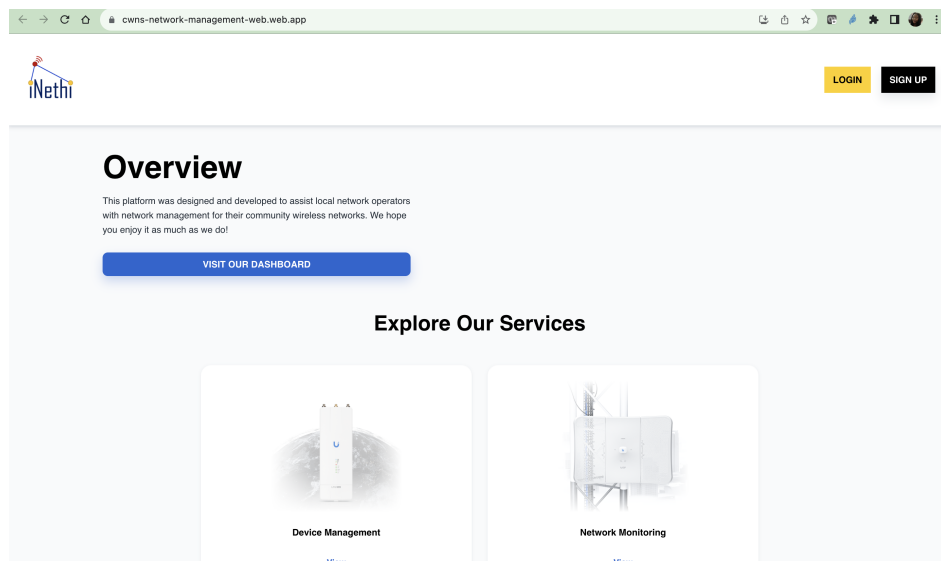


Figure 7.2: The landing page of the new NMI

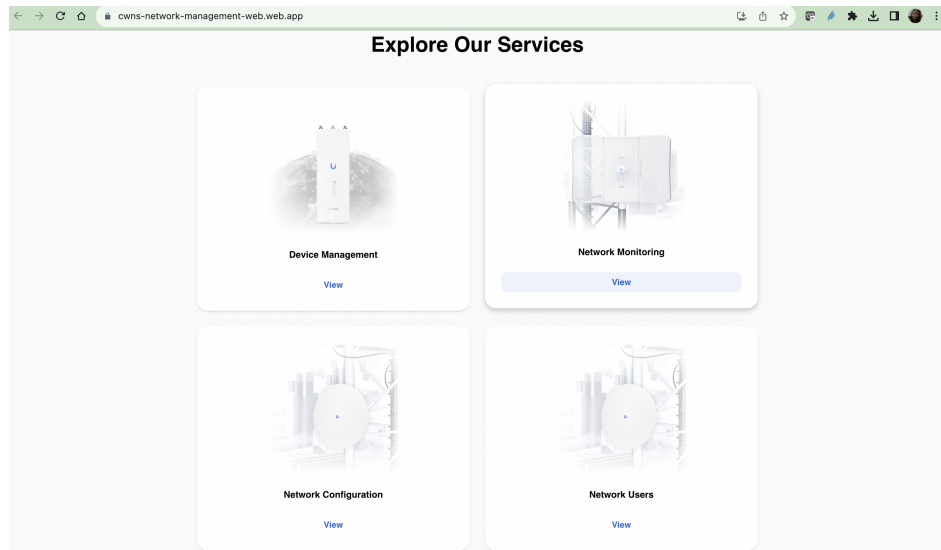


Figure 7.3: The menu options on the landing page of the new NMI

Device Management: Device management plays a role in ensuring the seamless operation of networked systems. In the context of network management for CWNs, extensive efforts need to be directed towards device discovery. This includes identifying and managing connected network devices and providing real-time status reports. On this page the network operators can view all network devices such as access points, filter connected devices and failed devices see Figure 7.4.

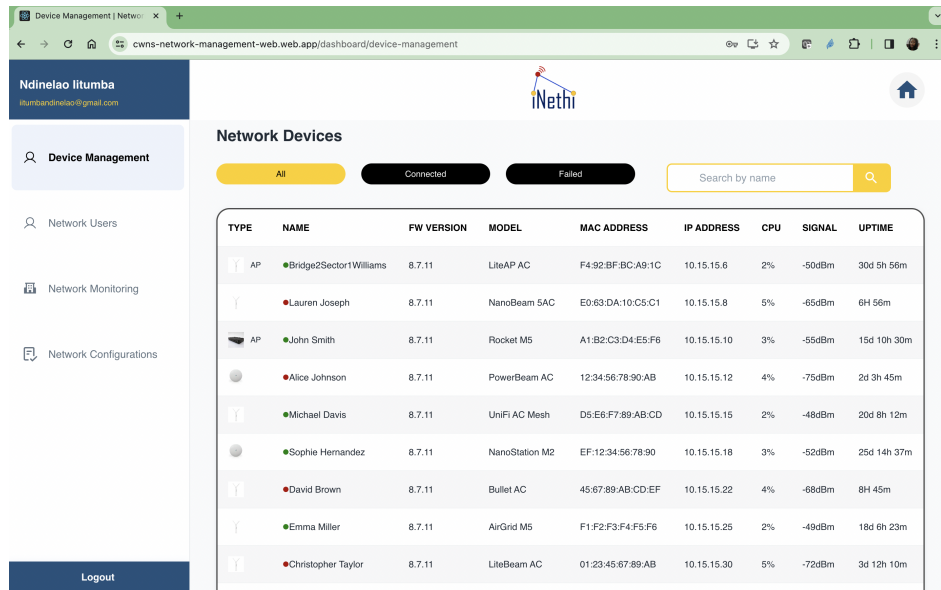


Figure 7.4: Device management page

Network Users: Understanding and managing network users is vital for ensuring security and optimising resource utilisation. This page displays all the users connected, and can filter connected and disconnected or failed users and a search by name to view a specific user. By prioritising the management of network users, the NMI contributes to a more secure and controlled network environment. See figure 7.5

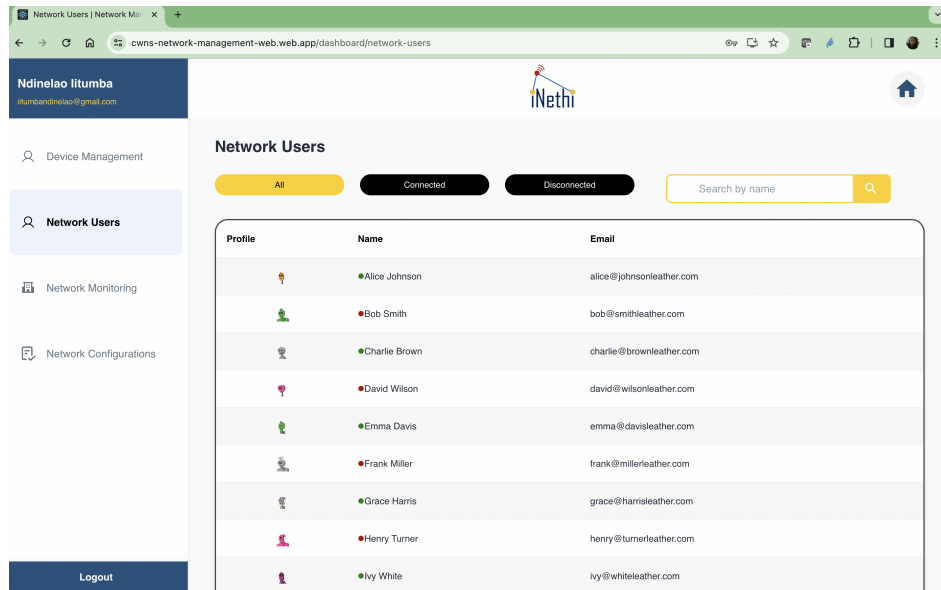


Figure 7.5: Network users page

Network Configuration: The NMI places significant emphasis on simplifying and enhancing network configuration processes. This page allows the network operators to add both network devices and users. The successfully added network devices will be displayed in the device management page and the users in the network users page. Automation features have been implemented to handle repetitive tasks, ensuring consistency and reducing the likelihood of configuration errors. This focus on network configuration aims to improve overall system responsiveness and ease of management.

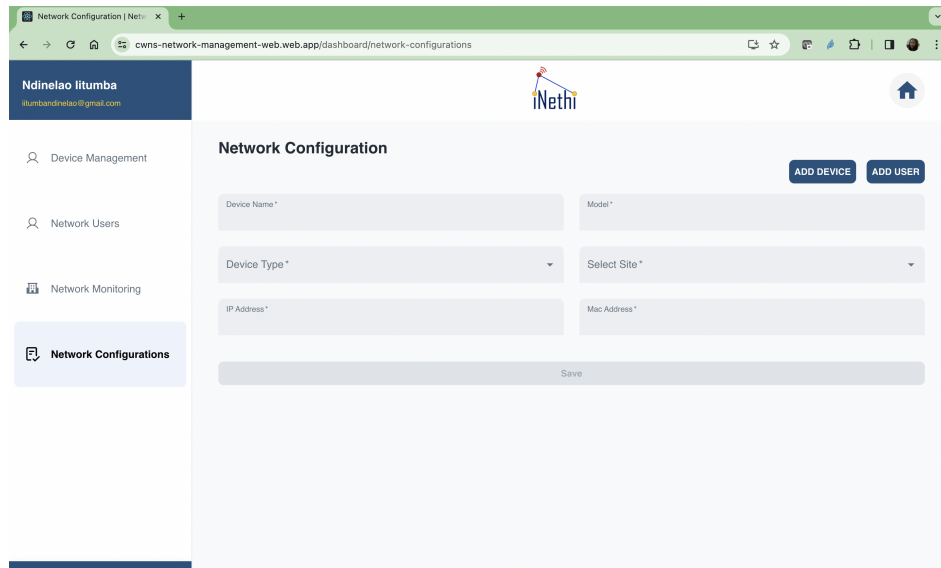


Figure 7.6: Network Configurations page

Network Monitoring: Efficient network monitoring is critical for preemptive issue detection and timely problem resolution. This page displays the sites of the community network, number of users in each site and network failures. The NMI incorporates advanced monitoring capabilities, employing a combination of active and passive monitoring techniques. Real-time data collection, performance analytics, and anomaly detection mechanisms have been integrated to provide administrators with comprehensive insights into network behavior. The objective is to empower users with the tools necessary to proactively identify and address potential bottlenecks, and performance issues.

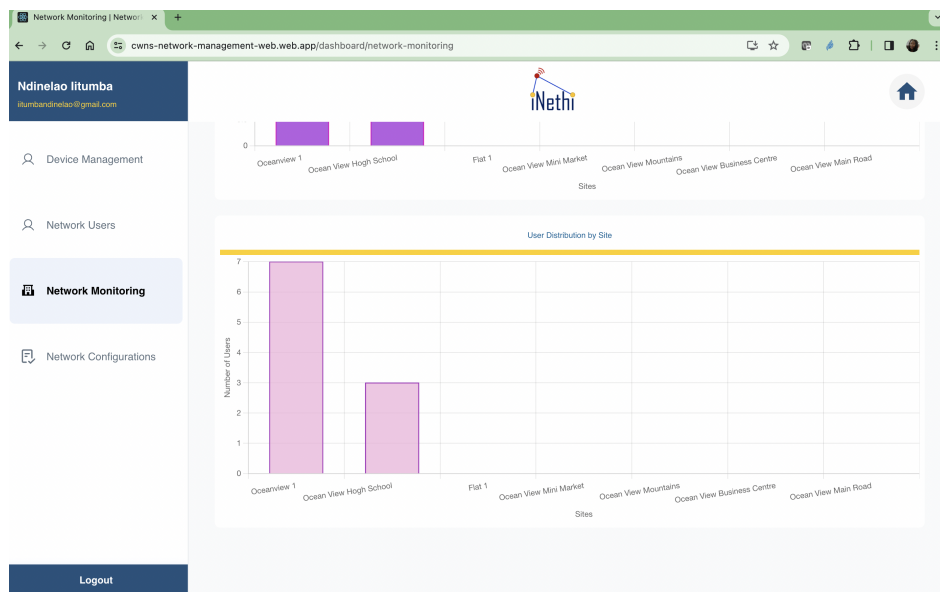


Figure 7.7: Network monitoring page

7.3 Mesh-Mash 2.0: Designing for Diverse Hardware

Mobile network technologies are always changing, vertical integration is happening, applications are becoming more diverse, and more advanced end-user devices are coming out. This makes network management tasks more difficult. These factors necessitate the dynamic reconfiguration of networks to align with operators’ cost and performance objectives [70]. The dynamic reconfiguration of networks is relevant to our findings in formulating practical network management tools and structures to assist local network operators. Indeed, Belli[13] argues that community networks need to self-organise to address the challenges of community networks in the design, development, and management of network infrastructure as a shared resource to enhance community network sustainability. [11]. However, our findings also indicate the need for increased expertise in utilising network management interfaces, enabling local network operators to effectively monitor and troubleshoot the network. As telecommunication companies expand their services annually, network management tools continuously evolve, becoming more complex for local network operators. [27]. Consequently, it is crucial for local network operators to receive formal and informal training and learning opportunities to effectively manage the network. Our results align with previous evidence that some existing tools have been challenging to set up and lack adequate visualisation of current per-device usage. [27]. Nevertheless, the

findings further indicate the need for more expertise in using network management interfaces for local network operators to monitor and troubleshoot the network. This is because telecommunications companies expand their services on a yearly basis, and these network management tools keep updating with new changes and becoming more complex for local network operators. [27]. Therefore, the data contributes to a clearer understanding of the need for local network operators to have formal and informal training and learning to manage the network. These results build on evidence that some existing tools were or are too tricky to set up and need to provide adequate visualisation or current per-device usage. [27]. Nonetheless, the findings highlight that local network operators and prospective local network operators have formed community support relationships with other community networks to share knowledge and learn together through the School of Community Networks (CNs) supported by the APC and ISOC organisations.

7.4 Bridging Network-Centred and Community-Centred Models of Network Management

Network-centred models primarily focus on technical aspects such as infrastructure, protocols, and performance optimisation, while community-centred models emphasise the social dynamics and collaborative practices within network communities. Recognising the strengths of both approaches, researchers aim to bridge these models to enhance the effectiveness of network management[28]. To address the challenges associated with managing complex networks, Chetty et al. (2013) proposed a framework that combines network-centred and community-centred perspectives. [28]. Their research reveals insights into consumer experiences in South Africa, indicating that advertised speeds are not consistently achieved, mobile broadband generally exhibits higher throughput than fixed broadband, and interconnection between ISPs significantly influences user reliability and performance. [28]. However, Khan et al. (2018) proposed a multi-layer self-learning framework that enables self-network management, emphasising the importance of leveraging the data usage patterns of mobile users within community networks to gain a comprehensive understanding of community needs [70]. Hadzic et al. (2016) further support the utilisation of mobile user data to inform community network requirements. [52]. Moreover, the involvement of users in the design process is crucial for developing acceptable systems. Winschiers et al. (2012) [129] and Bidwell (2011) [21] emphasised the importance of user engagement in design activities. By actively involving community members in network management tasks and decision-making processes, community networks foster a sense of ownership and collective responsibility, resulting in more resilient and self-sustaining networks. [13, 130, 20].

Network-centred models focus on technical aspects, such as infrastructure, protocols, and performance optimisation, while community-centred models emphasise the social dynamics and collaborative practices within network communities. By bridging these two approaches, researchers aim to leverage the strengths of both models to enhance network management effectiveness. [28] proposes a framework that combines network-centred and community-centred perspectives to address the challenges of managing complex networks. Their research findings indicate that consumers in South Africa often experience advertised speeds that do not align with the actual speeds received. Moreover, they observe that mobile broadband generally exhibits higher throughput compared to fixed broadband. The study indicates the significant role of interconnection between Internet Service Providers (ISPs) or their absence in determining the reliability and performance that end-users ultimately experience. In addition, the researchers propose a well-suited architectural design and advocate for a multi-layer self-learning framework capable of meta-learning for self-Network Management (NM) [70]. Furthermore, they advocate for leveraging the data usage patterns of mobile users within community networks to gain a genuine understanding of the community's needs [52]. The research also draws attention to the importance of involving users in design activities to develop systems that meet acceptable standards [129, 21]. This involvement, as supported by the findings, actively engages community members in network management tasks and decision-making processes. It fosters a sense of ownership and collective responsibility, resulting in more resilient and self-sustaining community networks [130, 20].

Despite having access to a pool of experts for assistance, participating in various formal and informal training sessions, and utilising diverse network equipment with different network interface controllers, participants still encountered challenges. These findings align with Poole et al.'s (2008) study, which revealed that homeowners often struggle to verbally articulate accurate information about their networks.

The findings indicate that it took more workshops for participants to grasp the technical concepts of network management, particularly when participants expressed difficulty understanding network management interfaces. Even though they have access to an ecosystem of experts for assistance, they go through different formal and informal training sessions and use ad-hoc, diverse network equipment that requires the use of different network interface controllers. The findings align with the conclusions drawn in Poole et al.'s (2008) study, suggesting that homeowners frequently require assistance in verbally articulating precise details about their networks. This implies that traditional interview methods and think-aloud techniques may yield limited information. Consequently, tackling user experience issues in home network management presents a formidable design challenge.

However, the literature further posits that there needs to be more understanding

of the cause of community wireless network failure due to the need for more human resources expertise. That was given to local community network operators and community members through research workshops (informal training) and long-term training (formal training) from communication network technology teaching experts from different organisations, such as the Association for Progressive Communications (APC) and the Internet Society (ISOC) [1, 2]. These results provide new insight into the implications of designing for the network management user experience. Therefore, network management tools for community networks should consider system complexity issues, the level of expertise required, and community networks' diverse hardware. By creating appropriate network management tools for local network operators, designers are taking essential steps to empower local network operators to understand and manage their community networks better.

Additionally, the expertise required to set up and participate in the setup of a community wireless network is very different from the expertise required to manage the community network by maintaining and monitoring the users and sustaining the network's performance. By redesigning and reconstructing the network infrastructure as needed when the network is overwhelmed [92]. Especially when it comes to community networks failing to attain their full potential due to a lack of competence, which is a fundamental prerequisite for community network management [48]. Designers rely largely on existing technical infrastructures to deliver practical, functional, deploy able, and cost-effective solutions through user-centred design. [33]. At the same time, this reliance may sometimes limit their capacity to adequately address user demands and capabilities [33]. The findings thus assert that, while not traditionally considered within the scope of HCI, such lower-level concerns significantly impact the user experience, determining what types of functionality can be delivered, the logic by which functions are organised, and the interdependence among these functions.

Regarding participation in technical network management, our findings highlighted the various problems and experiences of local network operators and community members. Due to the use of different branded network devices, local network operators must adapt to using multiple complex network management and monitoring interfaces while attempting to improve their expertise on the first interfaces that they began using, which are the Unify and Ubiquity (UISP) platforms, as in the case of (I/P1, P2) and (SA/P1). However, the findings indicate that these users encounter protocols, tools, and terminology that originated during the era when networks were designed and maintained by proficient (and salaried) network administrators. Our results show that the management of home networks is a frustrating and tedious experience for the majority of households.

7.5 Agenda for future Designers

The agenda for future designers should be framed within a broader shift towards designing digital technologies that prioritise the public dimension of social life [32]. It is crucial to consider the challenges faced by Wireless Internet Service Providers (WISPs) in reaching scaling limits and the practical benefits of functionalities like subscriber management over the hype surrounding Software Defined Networking (SDN) [53]. The concept of autonomic network management is essential for equipping researchers with the understanding needed to address network management complexities [70]. These findings underscore the need to prioritise certain features and enhance the usability of network management platforms. Current interfaces primarily cater to enterprise companies, lacking the necessary assumptions and considerations for community networks and underserved communities [119]. The exponential growth of connected smart devices, coupled with demanding quality-of-service requirements and the need for ubiquitous connectivity, pose significant challenges for local network operators [33]. Implementing automatic configuration models, where donors mesh with each other to aggregate Internet access, can greatly benefit community networks. [9]. Access aggregation with multi-path TCP (RFC 6824) speeds things up, and IPv4 and IPv6 solutions can be used to solve problems with addressing, discovery, and routing [9].

However, local network operators still require technical support, particularly in troubleshooting network issues [94]. Long-term sustainability relies on setting highly ambitious performance indicators for these systems [80]. Also, big steps forward in physical layer technologies are needed to get around problems caused by bad radio propagation conditions in the mm wavelength range so that mobile wireless communications can work [80]. Furthermore, technology enthusiasts play a significant role in network participation, experimenting with software development, network speed measurements, mapping, and management tools. Users acquire new skills in computer and network use through self-experimentation or training by network experts [32]. Therefore, future designers should adopt a user-centred approach when designing network management platforms. Prioritise the needs and challenges faced by community networks and underserved communities rather than solely focusing on enterprise networks. Consider the usability requirements specific to these contexts, ensuring that the interfaces and functionalities are accessible and intuitive for local network operators. Additionally, designers should emphasise the importance of incorporating autonomic network management principles [70]. Develop frameworks that enable self-learning and self-configuration to simplify network management tasks and reduce the reliance on manual troubleshooting [132, 9]. This will empower local network operators to efficiently monitor and troubleshoot their networks [132].

As subsequently discussed with our community networks from South Africa and India, we could design new network management interfaces or simplify the existing ones by restructuring them functionally to help local network operators find these features easily and capture connected network users. Currently, connected users are viewed through notifications, especially on the UISP platform and the captive portals of network devices, precisely the access points. Viewing this with other notifications makes it difficult for local network operators, especially with the admin logging into each separate device. The community network can have more than ten access points. It will be ideal for future designers to find ways to link multiple network devices from different brands to one network management interface. This might be complex due to different device technologies. However, it may require telecommunications service providers and network device companies and brands to work together to develop network devices and network management tools for community networks.

7.6 Displaying Network Devices and Remote Network Management

The current network management interface suffers from a tedious user experience due to the unlabeled icons representing connected devices [35]. To improve remote network management for local network operators, the display of connected network devices, including community access points, needs to be revamped. Adopted network devices should be automatically displayed on the dashboard, eliminating the need for users to search for them. This simplifies the management process [35]. Network management can be challenging for several reasons. Firstly, managed networks are heterogeneous, comprising hardware and software components from different manufacturers. Secondly, technology is constantly evolving, introducing new services and changes. Lastly, managed networks can be large and geographically dispersed, with distant network nodes [116]. Our findings reveal that local network operators do not reside within the community they serve and often visit periodically to troubleshoot and add nodes to the network. For instance, if the network goes down due to weather-related issues or power outages, the operators, who live in Bangalore, need to be on-site for troubleshooting. They cannot access the captive portals remotely, as they must be within the network to do so. This poses a challenge given the characteristics and difficulties associated with overseeing IoT devices [116]. IoT management includes two primary categories: IoT Network Management and IoT Device Management. The former entails gathering and analysing extensive data from IoT platforms to enable effective decision-making and actions, including remote network management [93, 116, 76].

The current navigation between different captive portals for network management

and the inconvenience of requiring on-site access to the captive portal pose challenges. While remote access software like TeamViewer and Anydesk provide options for remotely accessing computers, they still rely on someone turning on the computers and opening the network management sites. However, remote troubleshooting becomes problematic during network outages caused by adverse weather conditions affecting antennas and unstable power issues [119]. Therefore, future designers should consider restructuring access to captive portals from outside the network or building interfaces that accommodate various devices, such as Mesh Desk [119]. By addressing these issues, future designers can enhance the display of network devices, simplify remote network management, and overcome challenges associated with on-site troubleshooting and network accessibility.

7.7 Centralised and Decentralised Network Management

Centralised network management simplifies the enforcement of security protocols and ensures consistent implementation throughout the network [6]. However, this approach may introduce potential single points of failure and increase vulnerability to targeted attacks on the central controller [47]. On the other hand, decentralised architectures distribute security functions across multiple network devices and components. This distribution enhances network resilience and offers greater flexibility in security management. However, managing and maintaining decentralised architectures can be more challenging as security policies must be consistently enforced across diverse network components [84]. To address the future network landscape, design principles for decentralised network and service architectures have been proposed for 6G networks [101]. The usage of ad hoc equipment by community networks also impacts the centralization or decentralisation of the network [116]. In situations where networking equipment is scarce, network operators are compelled to procure any accessible network equipment brand. The Ubiquity application simplifies network management by enabling users to configure, upgrade, and monitor various Ubiquity devices. When a user adopts a device, the platform automatically recognises it within the network, eliminating the need for manual execution of extensive commands for device configuration. However, using multiple interfaces concurrently can pose a learning curve for local network operators, although proficiency improves with experience [84]. After participants expressed their apprehension about using Mesh Desk (Radius Desk) due to the possibility of forming a centralised network that relies on a single central server or domain controller, simplifying network management by allowing them to monitor all network devices on a single interface but having many limitations. As a result, local network operators favour a centralised network.

However, how can we prioritise easier network management over the restrictions of a centralised server? A centralised server's drawback includes experiencing network failure when one node fails, but a decentralised network provides redundancy if one node fails. Future designers should investigate the idea of building network management interfaces that promote centralised networks and ad hoc equipment (Ubiquity vs. Mesh Desk vs. Proprietary Application Vula).

7.8 Towards a Community-Owned and Feminist Wireless Network

Some important parts of community-owned and feminist wireless networks are the ability to go beyond traditional ideas of technological expertise and build relationships with people who don't have the same level of knowledge. Embracing a feminist approach to hacking and making acknowledges the structural inequalities that shape participation, recognising that not all individuals have equal opportunities to engage in community technology projects [44, 72]. It is essential to avoid assuming that women can seamlessly assimilate into male-dominated spaces, as this undermines their unique contributions to the culture of these projects [89]. Instead, fostering a dynamic and innovative social organisation that focuses on developing technology suited to the specific needs of the community is of equal importance to technical advancements [89]. These research findings further support the concepts put forth by feminist servers regarding the establishment and maintenance of mesh networks connected to locally owned servers managed by the community. This emphasises the importance of transitioning towards community-built and locally owned servers to improve network management for both local network operators and community members [8, 10]. Furthermore, this research validates that feminist wireless networks empower communities to determine the information stored on the network and control access to it. This insight offers a deeper understanding of the potential implications of such infrastructure for local communities. Additionally, technical expertise and troubleshooting skills are essential for setting up and maintaining the mesh networks that connect these servers. However, it is important to recognise that beyond the physical infrastructure facilitating digital connectivity, the human infrastructure, including meetings, gatherings, and the exchange of affection and knowledge, is equally vital for the successful deployment of community networks. These human interactions foster a sense of community and collaboration that strengthens the network's functionality and impact.

Feminist servers are data storage servers with an autonomous infrastructure for easy access and management by feminist groups. Feminist servers allow the Internet where the network is owned and managed by communities, thus positing an afford-

able alternative to the WiFi networks currently available to communities [44, 8, 10]. Our findings also support the concepts of feminist servers on setting up and maintaining mesh networks connected to locally owned servers by the community. Some of our participants outlined that they are developing a network management interface that meets their needs, uses open-source software, and caters to their ad-hoc equipment to improve network management. This indicates that moving towards community-built and locally owned servers will improve the management of community networks and local servers for local network operators and community members [8]. This reinforces the notion that feminist wireless networks empower communities to determine the information stored on the network and regulate its access. Consequently, our research provides an understanding of the implications such infrastructure could have for local communities. Establishing and sustaining mesh networks connecting these servers requires technical expertise and troubleshooting skills. Thus, beyond the physical infrastructure enabling digital network operations, the human infrastructure—each meeting, gathering, and exchange of affection and knowledge among people—becomes even more crucial in deploying the community network.

7.9 Chapter 7 Summary

This chapter discusses the research findings, placing a strong emphasis on the imperative consideration of local knowledge and skills possessed by community network operators in the design of Network Management Interfaces (NMIs) for the sustainability of community networks. The chapter talks about a lot of important topics, such as mesh networking, the coming together of network-centred and community-centred models, future design plans, how to best show off network devices, the argument between centralization and decentralisation, and the creative idea of community-owned and feminist wireless networks.

In the section titled "Mesh-Mash 2.0: Designing for Diverse Hardware," the chapter covers the challenges posed by evolving network technologies, advocating for dynamic reconfiguration aligned with cost and performance objectives. The significance of expertise and training for local network operators takes centre stage, addressing the evolving complexities of network management interfaces. In the subsequent section, "Bridging Network-Centred and Community-Centred Models," delves into the strengths inherent in both technical and community-centred approaches to network management. A key emphasis is placed on user engagement in design activities, fostering a sense of ownership and responsibility, ultimately contributing to the resilience of community networks.

The chapter then outlines an "Agenda for Future Designers," calling for the pri-

oritisation of digital technologies that serve the public dimension of social life. It advocates for a user-centred approach to NMI design, recognising the specific needs and challenges faced by community networks and underserved communities. In "Displaying Network Devices and Remote Network Management," the challenges in the current NMI user experience are dissected, with proposed solutions aimed at improving the remote management of connected devices. Acknowledging the intricacies of managing heterogeneous networks, the discussion emphasises the necessity for user-friendly interfaces. Further, the chapter covers "centralised and decentralised network management" and critically evaluates the advantages and challenges associated with both approaches. Future designers are urged to investigate interfaces that align with the characteristics of community networks, addressing the ongoing debate between centralization and decentralisation.

Lastly, the section "Towards a Community-Owned and Feminist Wireless Network" champions a feminist approach to technology projects, acknowledging structural inequalities. The discourse extends to the significance of transitioning to community-built and locally owned servers, empowering communities to assert control over their network infrastructure. The chapter discussed the difficult relationship between technical infrastructure and human interactions within community networks. It reiterates the paramount importance of community engagement, collaboration, and a feminist perspective as foundational elements in realising sustainable and resilient wireless networks.

Chapter 8

Conclusions and Future Work

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I have published some parts from the conclusions in the AfriCHI paper and CoLRN Report [60, 36].

8.1 Research Contributions

This research contributes to the field of human-computer interactions (HCI) and co-design research, focusing on CWNs, by addressing the objectives set out at the initiation of this study. The primary aim was to explore network management within CWNs and thoroughly analyse how local network operators management the networks from their experiences, what information resources or training do they use, this was achieved in Chapter 3 through semi-structured interviews and six co-design workshops. This study sought to discover challenges that these interfaces pose while identifying areas for improvement that were achieved in the findings through chapters 4, 5, and 6. In doing so, the study delved into determining the best practices necessary to empower community members to manage their network infrastructure effectively. Through a collaborative and community-involved approach, I embarked

on co-designing a new network management interface with participants from Janastu and Inethi CWNs explicitly tailored for CWNs with local network operators.

Central to the research objectives was a comprehensive understanding of the challenges experienced by CWN local operators. This user centred viewpoint provided invaluable insights into the practical obstacles faced by these community members. It helped lay the groundwork for a community-centred perspective on network management, emphasising the need for solutions that align with the specific requirements and challenges of these users. The study's design approaches, aimed at empowering local CWN management, made a significant contribution to refining interface techniques. It introduced methodologies and strategies intended to uplift and enable CWN operators access to manage their networks more independently.

8.2 Reflection and Lessons Learned

This study explored community wireless network management. Delving into the practical challenges and experiences of individuals engaged in managing these networks has been an eye-opening journey. The examination of different user groups, their familiarity (or lack thereof) with network management tools, and the diverse challenges faced in Ocean View (InethiCWN) and Devrayandurga (Janastu) has provided insight into the complexities of network management at the local level.

The findings uncovered challenges faced by users, particularly in Ocean View, with unfamiliarity and difficulty navigating through network management tools. The identification of terminology issues, such as interpreting the meaning of various terms on interfaces and the struggle to interpret graphs and data presented within the management platforms, underlines the practical obstacles users encounter.

This research also sheds light on the specific needs of local communities. The insights provided by Janastu participants, for instance, emphasised the necessity for tools that cater to their unique settings. Ideas like a network monitoring tool for device-to-device pinging, remote network management, and capturing more detailed network management concepts were highlighted, showcasing the necessity for community-specific tools.

The role of external expertise has emerged as crucial in the journey of local network operators, guiding their understanding, problem-solving, and learning through practical experiences. The learning processes, including participating in workshops, collaborating with experts, and receiving formal training, have significantly shaped the capacity and skill sets of these operators.

This research also unveiled the impact of weather conditions, power outages, and

technical interruptions on CWNs, leading local network operators to experience technical troubleshooting challenges. Understanding how power issues, including power outages and low battery voltage, significantly interfere with network management, along with the effects of harsh weather conditions, provides critical insights into the practical challenges faced in maintaining stable network connectivity.

Lessons Learned:

- **Local Community Network Needs:** Understanding the Significance of Community-Specific Tools and Interfaces for Effective Network Management
- **Role of Education and Training:** Recognising the importance of workshops, training, and continuous learning in enhancing network management skills
- **External Support and Expertise:** Acknowledging the invaluable guidance and knowledge shared by external experts in furthering network management capabilities
- **Adaptability in Addressing Challenges:** Understanding the need for adaptable and resilient solutions to combat weather-induced and power-related disruptions in network connectivity

8.3 Research Limitations

This research only employed participants from existing community wireless networks that I knew or had existing collaborations with my supervisor. Moreover, this research also commenced during the pandemic; hence, I conducted the semi-structured interviews online. Online interviews were really challenging because all my participants were bandwidth-constrained. However, I managed to compensate them with R100 in airtime for mobile data.

8.4 Future Considerations

Based on the findings from the research conducted with local network operators managing Community Wireless Networks (CWNs), several recommendations can enhance their practices. One primary focus lies on the need for knowledge enhancement regarding network technicalities. A structured approach to training or educational programs could effectively equip these operators with the essential technical knowledge required to manage and troubleshoot wireless network failures. Access to professional resources, guidance, and community-driven knowledge-sharing platforms could further enhance their expertise and efficiency in handling these networks.

Local network operators require access to network management systems that support larger wireless networks, particularly those with more than 20 access points, to facilitate the growth of network infrastructure within Community Wireless Networks (CWNs).

Moreover, recognising and empowering the diverse roles local operators play in the management of CWNs is important. There's a need to acknowledge their significance and provide support tailored to their roles within the community network. Offering training or resources for the diverse roles in network management, ranging from overseeing network stability to community training, can better equip operators for their responsibilities.

Another recommendation involves improving network management interfaces. Designing user-friendly interfaces and platforms can significantly ease operators' tasks and allow more efficient network management. Accompanying these interfaces with comprehensive technical support could further facilitate the operators' navigation and utilisation of these platforms.

To address the challenges experienced with existing network platforms, efforts must be directed towards simplifying interfaces and providing comprehensive educational support. Streamlining the complexity of these interfaces, offering user guides, and creating tutorials could immensely assist the operators in navigating these platforms effectively, addressing issues like understanding graphs, terminologies, and accessing information seamlessly.

Providing extra learning resources on network management, such as a chatbot, videos, or frequently asked questions, and troubleshooting manual.

Hardware diversity and shortages emerged as a significant challenge for network operators. Efforts to streamline supply chains and address the shortage of essential network equipment are crucial. Promoting standardisation in the equipment used across various CWNs would significantly ease procurement and network management practices.

For efficient troubleshooting and handling network failures, incorporating remote management tools and onsite training is essential. Remote management tools would enable operators to resolve issues more effectively, particularly for those who predominantly manage networks onsite. Facilitating easier transitioning between various devices and ensuring equipment compatibility could significantly streamline the process of resolving network errors.

8.5 Research Conclusion

In conclusion, this research provides the findings of a qualitative study conducted with 25 CWN stakeholders, which included semi-structured online interviews with CWNs in South Africa (Inethi Ocean View, VNET Khayelitsha, and Mamaila CWNs Limpopo) and India (Janastu Hills). The study aimed to uncover the needs, experiences, roles, challenges, and troubleshooting resources existing CWNs face and use while managing their community networks. This study has contributed to understanding some of the challenges encountered by local CWN operators and has emphasised the importance of adopting a community-centred approach to network management and design. I have observed the use of various network management interfaces by community networks by examining the various equipment they use, which frequently results from the lack of standardised equipment. This highlights the adaptability and resourcefulness of local operators in navigating the limitations they face. Furthermore, this research has underscored the significance of formal and informal training and learning opportunities for local network operators to effectively manage their networks. Recognising the need for continuous skill development and knowledge acquisition, we recommend the provision of supportive resources and training programs to empower CWN operators and enhance their network management capabilities.

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Appendix A

Ethics Approval



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27 October 2021

Ndinelao litumba
Department of Computer Science

Community-Centered Network Management for Community Wireless Networks

Dear Ndinelao litumba

I am pleased to inform you that the Faculty of Science Research Ethics Committee has approved the above-named application for research ethics clearance, subject to the conditions listed below.

- Restrictions on involving human participants in research must be adhered to, given current concerns about the spread of Covid-19. Please ensure that you are aware of and comply with UCT policy on this, as communicated by management.
- Implement the measures described in your application to ensure that the process of your research is ethically sound; and
- Uphold ethical principles throughout all stages of the research, responding appropriately to unanticipated issues: please contact me if you need advice on ethical issues that arise.

Your approval code is: **FSREC 102 – 2021**

I wish you success in your research.

Yours sincerely

Signed by candidate

Dr Shari Daya
Chair: Faculty of Science Research Ethics Committee

Appendix B

Informed Consent Form

DEPARTMENT OF COMPUTER SCIENCE

UNIVERSITY OF CAPE TOWN
PRIVATE BAG X3
RONDEBOSCH 7701
SOUTH AFRICA

RESEARCHER/S: Ndinelao Iitumba
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Informed Voluntary Consent to Participate in Research Study
Project Title: Community-Centered Network Management for
Community Wireless Networks

Invitation to participate, and benefits: You are invited to participate in a research study conducted with INethi/Zenzeleni/VNET/Mamaila community members. The study aims to provide community wireless networks in bandwidth constrained communities with a network management platform. The network management platform will be designed with the input of users so that it will be easy use for community members.

Procedures: During this study, you will be asked to answer a few questions about your usage of any CWN, your involvement in your CWN management, the challenges you face in attempting to troubleshoot/diagnose your network connectivity problems. As a participant you will also be participating in an online/face-to-face workshop to prototype and brainstorm with other participants a new network management interface. Depending on your preference we can arrange an online call or meet up in your community for an interview. For workshops you will be require completing a health check form on your phone that will determine that you are eligible to participate in in-person workshops and you will be provided with the venue of the workshop.

Recording: We may take photographs and/or record audio/video as part of the study. These will be used to analyse the data/ information collected and will not be published or shared. However, we will share photographs of the designs produced. If you object to this, please indicate below.

Risks: There are no potentially harmful risks related to your participation in this study.

Feedback: You will receive feedback about the results of this research by receiving a SMS about the results.

Disclaimer/Withdrawal: Your participation is completely voluntary; you may refuse to participate, and you may withdraw at any time without having to state a reason and without any prejudice or penalty against you. Should you choose to withdraw, the researcher commits not to use any of the information you have provided without your signed consent. Note that the researcher may also withdraw you from the study at any time.

Confidentiality: All information collected in this study will be kept private in that you will not be identified by name or by connection to any institution.

What signing this form means: By signing this consent form, you agree to participate in this research study. The aim, procedures to be used, the potential risks and benefits of your participation have been explained to you. You can pull out from participating. You are free to contact me and ask questions.

I agree to participate in this research (tick one box) Yes No _____ (Initials)
I agree to be photographed Yes No _____ (Initials)
I agree to be audio-recorded Yes No _____ (Initials)
I agree to be video recorded Yes No _____ (Initials)

Name of Participant Signature of Participant Date

Name of Researcher Signature of Researcher Date

Appendix C

Phase 1 Interview Guide

Investigating Network Management for Community Wireless Networks

Interview Script

Date:XXXX

Interviews start time: 15:00

Interview end time: 15: 25

Interviewee Code (no names): P12

Cell-phone number: XXX

Location: XXX

Interview platform: Online

Gender: XXXX

Attach Signed Consent Form

Note: RQ1: What challenges inhibit CWN operators & community members from managing their CWNs?

RQ2: How do CWN operators envision the management of CWNs?

RQ3: Can community-based co-design be applied to design a CWN management interface that allows semi-skilled and non-experts to manage their CWNs?

1. Tell me about Yourself?
2. Do you have access to the internet? /How do you access the internet?
3. When/ how did you start getting involved with your CWN at management level
4. What role do you play in your CWN?
5. Can you set up a network?
6. Have you used any network management platforms before?
7. How much do you know/understand about the community wireless network? (Understand how they perceive the network)
8. Which platform do you use to manage the network? / Which platforms if there are many?
9. What challenges do you face when managing the network?
10. Which resources do you consult when fixing/monitoring your network to understand what you are dealing with?

Field Notes by Researcher:

Appendix D

Phase 2 Workshop Protocol (Co-Design)

CWNS Network Management Interface Co-Design Workshops Protocol

By: Ndinelao Iitumba and A/Prof. Melissa Densmore

Pre-Co-design Activities

1. Ethics Clearance Amendments

For the case of co-design activities taking place during COVID-19 lockdown levels 1-3:

The co-design activities will take place in person through workshop groups with participants from each Community Wireless Network (CWN). A workshop group will consist of 10-15 participants + 1 facilitators, with COVID-19 safety regulations in place. This includes:

- Facilitating sanitizing stations to sanitize participants and facilitators before entering workshop.
- Enforcement of participants and facilitators wearing masks at all times (surgical masks will be provided).
- Socially distancing participants and facilitators: enforcing distance of 2 meters between each person.
- Excluding participants with comorbidities to the COVID-19 virus.
- Focus group will take place in a large well-ventilated area

Ethics Clearance granted for this in-person co-design tasks.

For the case of co-design activities taking place during COVID-19 lockdown levels 4-5:

The co-design activities will be facilitated by couriering co-design materials (paper boards and pens for sketching) to participants and communicating the instructions of how to use them via Video Conferencing tools such as Zoom, Microsoft Teams, Skype.

Ethics Clearances would not need to be amended for this approach.

2. Participant Recruitment

Participants will be recruited by contacting Community Wireless Networks (CWNS) management stakeholders from experts to local semi-skilled network operators (via phone call or WhatsApp).

Participant Criteria

- Ocean View community member
- Semi-Skilled Expert
- Local network operators

- Any CWN stakeholder
- Learning to manage the network from the deployers
- Knows minimum network management skills
- Uses INethi Network(Any community wireless network) as a primary internet connection
- Tries to troubleshoot network problems
- Struggles to diagnose network problems
- Reports unavailability of network to directors/ network admins after trying
- Bandwidth constrained

Contact Person	Email Address	Contact number	CWN/Affiliation	Area
xxxxxxx	xxxxxxx	xxxxxxx	Mamaila Community Wireless Network	Limpopo South Africa
xxxxxxx	xxxxxxx	xxxxxxx	Inethi CWN	Cape Town Ocean View South Africa
xxxxxxx	xxxxxxx	xxxxxxx	VNET (CWN on farms)	Cape Town Khayelitsha South Africa
xxxxxxx	xxxxxxx	xxxxxxx	Groot Aub CWN	Windhoek Namibia
xxxxxxx	xxxxxxx	xxxxxxx	Soweto Wireless Network	Soweto South Africa
xxxxxxx	xxxxxxx	xxxxxxx	Janastu	Bangalore Karnataka India

The leaders of some of the existing CWNs in this table will suggest potential participants from these CWNs that can participate in this research. All the stakeholders of CWNs that are interested in engaging in co-design activities during the community engagement interviews will participate in the workshops.

3. Facilitators Training

The co-design activities will be directed and assisted by the researcher who will receive in-person training prior to the co-design activities. This training will involve presenting the co-design approach to the HCI group for feedback from students that have already done workshop co-design before. This training will include a walk-through of the co-design

workshop protocol with the Supervisor, Net4D and HCI lab members. This will provide the researcher a clear vision of the activities and for a discussion on how best to communicate the activities to the participants.

Informed Consent

For the case of co-design activities taking place during COVID-19 lockdown levels 1-2:

The consent form will be emailed or sent to participants a week before the workshop and interviews. The participants can send it back or can give consent via messages and the researcher can screenshot them. The researcher will also read the consent form to participants at the beginning of the interviews, and they will provide their voluntary, oral informed consent to participate in the co-design activities prior to engaging with any co-design activities if they could not return the consent form sent to them. Audio recording of this consent will take place. This consent form will be translated into the language of their preference.

For the case of co-design activities taking place during COVID-19 lockdown levels 3-5:

The researcher will telephonically read the consent form to participants, and they will provide their voluntary, oral informed consent to participate in the co-design activities prior to engaging with any co-design activities. This consent form will be translated into the language of their preference.

Note: RQ1: What challenges inhibit CWN operators & community members from managing their CWNs?

RQ2: How do CWN operators envision the management of CWNs?

RQ3: Can community-based co-design be applied to design a CWN management interface that allows semi-skilled and non-experts to manage their CWNs?

For the case of co-design activities taking place during COVID-19 lockdown levels 1-2:

Workshop Agenda

Orientation	Time	Format
<p>I would like to thank you all for being available to attend this workshop. Today we are going to participate in 3 small activities to prototype a NMI in groups of 3.</p> <p>Watch UNMS short tutorial 7 minutes</p> <p>This are the 3 most used Network management interfaces as stated from interviews.</p>	<p>10:00 -10:20</p>	<p>Plenary</p>

<p>Co-design Activity</p> <p>First Activity- I will distribute this empty [White paper boards] at each group (of 2/3) and each group will write down the challenges that you face when using any of the platforms. (Share challenges from interviews)</p> <p>Second Activity- Provide each group with Sketching Posters and Feature cards [Figure 1] each group will Prototype how they would like to access that feature on the Network Management Interface (NMI).</p>	<p>10:20- 10:40</p> <p>10:40- 11:30</p>	<p>Plenary</p>
<p>Lunch Break</p>	<p>11:30-11:55</p>	<p>Have light lunch</p>
<p>Feedback</p> <p>Last Activity- Each group will present their prototype to the researcher & other participants and have feedback from other participants.</p> <ol style="list-style-type: none"> 1. Ask participants to write their feedback on each groups prototype on the white boards. 2. The researcher will do a cognitive walkthrough with the participants to understand the solution in more depth. The researcher will describe what 	<p>12:00-12:45(10 minutes presentation per group, 5 minutes for feedback)</p> <p>12:45-13:00</p> <p>13:00-13:30</p>	<p>Plenary</p>

- View connected users
- Dashboard
- Site Map
- Displaying Connected devices
- Update site
- View logs

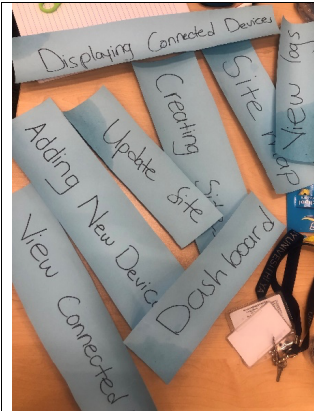


Figure 1: Example of Card boards (With features) used to support prototyping.

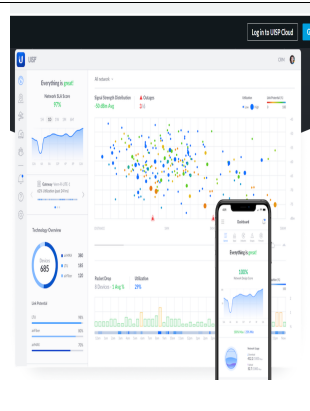


Figure 2: Example of existing or current Network management interfaces

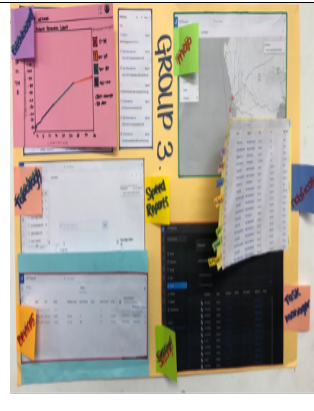


Figure 3: Example of a poster sketch.



Figure 5: PfSense firewall user interface(<https://www.pfsense.org/>)

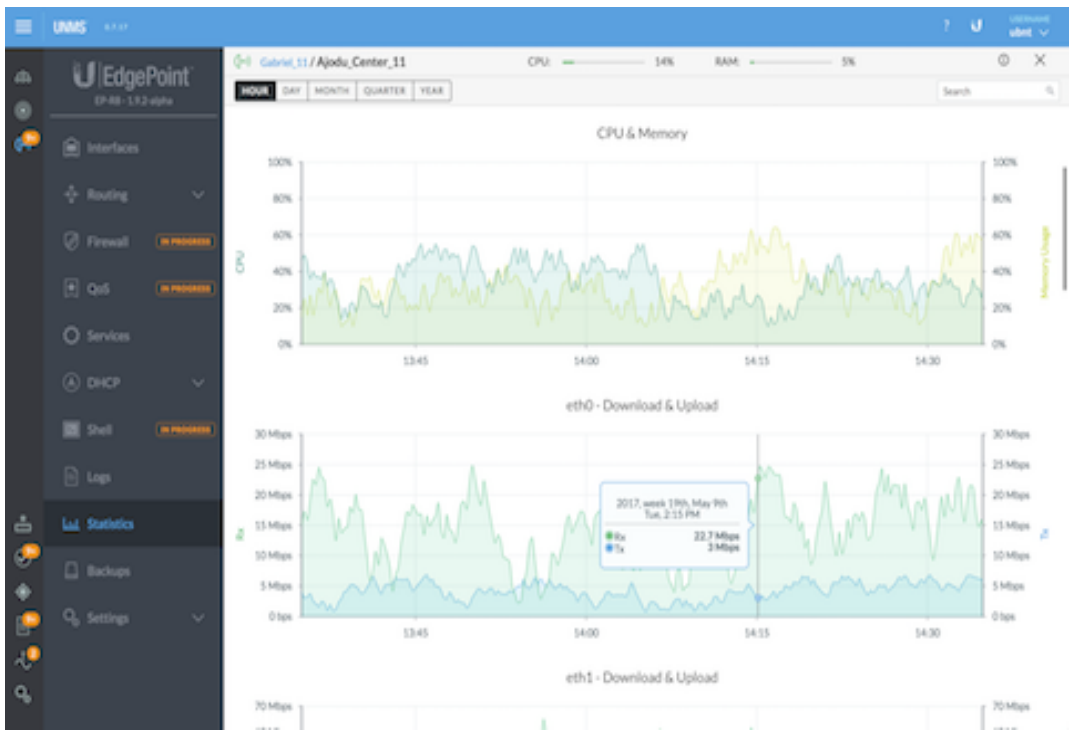


Figure 6: UISP network management platform Interface(<https://uisp.com/>)

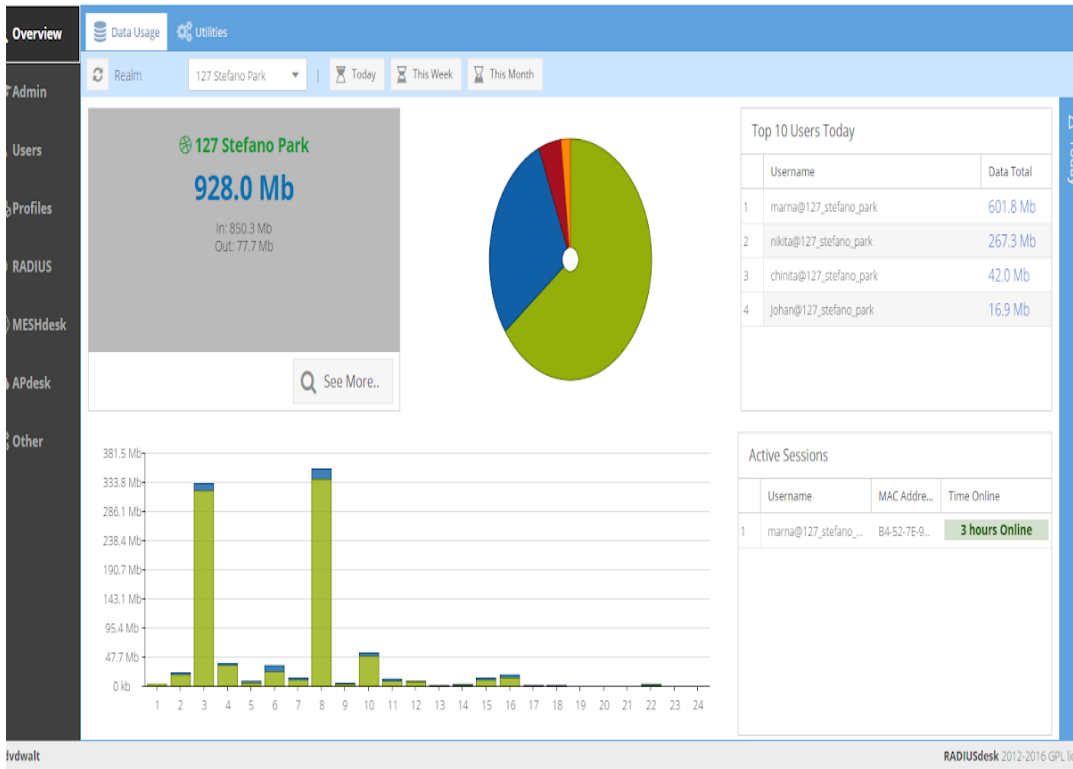


Figure 5: Radius Desk network management Interface(<https://www.radiusdesk.com/>)

Appendix E

Phase 3 Workshop Protocol (Deployment)

NMI Deployment Workshop Protocol for Inethi Ocean View and Janastu

By Ndinelaio litumba and A/Prof Densmore

Workshop Materials

1. Procedure on Radius Desk Installation
2. Flashing firmware procedure:

<https://openwrt.org/toh/ubiquiti/unifiac>

<https://downloads.openwrt.org/releases/21.02.3/targets/ramips/mt76x8/>

<https://openwrt.org/toh/start>

3. Demo set up devices: 6 Ethernet cables, 2 Ubiquiti AC Mesh, 1 mini switch, and Pf – Sense firewall

Introduction	Introduce the project Recap findings from previous interviews and NMI workshop Share findings from Janastu and the previous OV workshops Introduce Deployment Plan	10am -10:30pm	
Activity 1	Introduction to (Radius Desk) Mesh Desk- In this activity we will show the participants around the mesh desk Interface and show them different aspect i.e., how to add access points, users and monitor the devices and allow participants to ask questions	10:30 am - 11:30pm	Plenary
Main Activities			Plenary
Activity 2	Ask participants to set up Radius Desk and connect the devices to Radius Desk with my assistance and guidance. (Janastu)Also explore how to use Radius Desk to manage vouchers currently being practised at Inethi.	12-13pm	Plenary
Activity 3	Demonstrate how to flash an access point and connect it to the Radius Desk Interface and let participants do it in a group.	13-14pm	Plenary
Closing Activity			

Activity 4	Feedback from Participants regarding their experience using the interface, adding devices and clients etc Their thoughts on network management with Radius Desk Proceeding with Radiusdesk/ Them having access to the interface	14-15pm	Plenary
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