Reconsidering Network Management Interfaces for Communities

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Community-owned mesh wireless networks enable cost-effective sharing of networked resources, expanding internet and local service accessibility through low-cost WiFi hardware. However, maintaining these networks comes with expenses. In addition to hardware costs, community members need extensive training to install, monitor, and troubleshoot the networks using Network Management Interfaces (NMIs). Effective network management is crucial for CWN resilience within communities. This paper presents qualitative interviews with 25 stakeholders from two CWNs in India and four in South Africa, examining challenges to CWN resilience. Workshops were conducted with network operators and users in India (Janastu) and prospective operators in South Africa (FOCUS Network) to reimagine NMIs, discussing challenges and prototyping interfaces. Our findings highlights 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. The paper outlines design opportunities to improve network management interfaces for CWNs, fostering network resilience for critical infrastructures.

CCS Concepts: • **Computer systems organization** → **Embedded systems**; • **Human Computer Interactions** → *HCI*; • **Co-design** → Computer Systems; • **Networks** → Network reliability.

Additional Key Words and Phrases: community wireless networks; network management interfaces; community-centred design; community

ACM Reference Format:
Ndinelao Iitumba, Siddhant Shinde, Deysi Ortega, Naveen Bagalkot, Nervo Verdezoto, Ganief Manuel, TB Dinesh, and Melissa Densmore. 2023. Reconsidering Network Management Interfaces for Communities. In *Proceedings of AfriCHI 2023: 4th African Human Computer Interaction Conference.* ACM, New York, NY, USA, 12 pages. https://doi.org/XXXXXXX.XXXXXXX

1 INTRODUCTION

The Covid-19 pandemic has highlighted the digital inequities that exist, as not everyone has access to the internet, particularly those in low socio-economic communities [35]. The lack of internet access is a result of financial exclusion, unequal deployment of infrastructure, and limited skills and training in digital technologies [13]. This issue goes beyond digital justice and is about ensuring equitable access to digital infrastructure and services. Many communities that have faced historical exclusion in non-digital spheres also require representation in discussions about internet access. Inclusive conversations about internet access can benefit the global community [17]. To address these challenges, under-represented and rural communities have started implementing Community Wireless Networks (CWNs) with the assistance of communication networks experts [28]. These communities establish their own networks using

community resources and funding from contributions or donations. However, managing and interacting with the digital infrastructure of these community networks presents various challenges including power issues, funding for equipment replacement and network expansion, obtaining a backhaul, and technical network management [16]. Involving under-represented communities in discussions and design workshops is crucial for building resilient CWNs and supporting diverse and inclusive digital technology development [16].

Previous research has explored the importance of CWNs and alternative network design models to address connectivity gaps in under-represented communities [31, 33, 33]. Organizations such as the Internet Society and the Association for Progressive Communications have also made financial commitments to support the development of CWNs worldwide [17]. However, existing studies on CWNs have primarily focused on technical design, implementation, and sustainability, with an emphasis on financial and technological challenges [2, 4, 6, 8, 16, 28]. Other studies have looked at geographical and gender implications, as well as the infrastructure and politics of community networks [16, 26, 28, 34]. Yet limited access to network management resources presents additional challenges for community members in maintaining these networks. Thus, there is a need to understand community members' perceptions of network management, the challenges faced by CWN operators and community members, and their vision for CWN management.

This paper presents the findings of a study that combines online interviews and in-person workshops with multiple stakeholders from two CWNs in South Africa and India. The study aimed to uncover the needs, experiences, roles, challenges, and troubleshooting resources of existing CWNs in managing their networks. The research also explored best practices for network monitoring and co-designed a network management interface suitable for semi-skilled and prospective network operators. The study contributes to existing knowledge in Human-Computer Interaction (HCI) and Information Communication Technology for Development (ICT4D) by providing a deeper understanding of the challenges faced by local CWN operators. It offers a community-centered view of network management and design approaches to empower local CWN management. The findings reveal that community networks rely on diverse and ad hoc equipment, leading to the use of different network management interfaces. Additionally, local network operators require formal or informal training to manage the network. The study aims to support local network operators in community wireless network management and inform the future design of community networks in the Global South, promoting resilience and inclusivity.

2 RELATED WORK

2.1 Community Wireless Networks and Network Management in the Developing World

Community Wireless Networks (CWNs) are organisations or movements formed to provide free, subsidised, or low-cost access to the Internet via wireless means by and for the communities [1, 18, 30]. The International Telecommunication Union (ITU) and Internet Society define community networks as community initiatives to connect the unconnected [27]. ITU and Internet Society reported that after the COVID-19 pandemic, the number of people connected to the Internet has increased to 63 per cent from 54 per cent, indicating that the majority of the connections are mostly from developed countries and that most marginalised communities in the Global South remain unconnected [5, 7, 8, 27, 36]. Some CWNs, such as Tanzania CWN, Zimbabwe, Inethi SA, and Zenzeleni, supported their community members during the pandemic [40]. However, they struggled with sustainability issues such as financial limitations, power disruptions, network management difficulties and technical inadequacy [5, 19, 20, 28, 37].

Some existing community networks also venture into hosting local content and archiving health knowledge, such as FOCUS and COWMesh (Community Owned and Operated Wireless Mesh). FOCUS is a community network deployed in Ocean View, Cape Town by Black Equations, in cooperation with researchers from the University of Cape Town [28]. Black Equations represents the community on the project, having expanded the network from an initial deployment led by the OV Comm Dynamic cooperative [40]. The FOCUS community network consists of 20 hotspots supported by Ubiquiti access points [28]. COWMesh is a mechanism developed for communities by the Janastu Servelots team to take ownership of local communications and reduce the cost of access to information while also demystifying the building blocks of the Internet [41]. COWMesh uses ubiquiti for long distance wireless wire / P2P but Libre Routers for community networks, COWMeshes use WiFi and other low-cost deregulated media to share content locally and deploy services for sub-communities. They then curated content for their needs and utilises a hyper-media archive architecture for their storytelling, publishing and navigation needs or online classes during the lockdown times of 2020 [41].

2.2 Known Constraints and Pain Points

The current network cost includes training support for operators to implement, run, and control the network separately from equipment price and yearly upkeep prices [5]. Some challenges come with maintaining the network and ensuring the community members utilise the community network despite their lack of advanced ICT skills, cost of equipment and maintenance, and power issues [32]. The operational challenges of community networks include low-cost and sustainable solutions for several aspects of the system, including monitoring, power and recovery mechanisms.

This study looks at two CWNs working in collaboration with university partners, specifically FOCUS and Janastu Servelots. Janastu's network specialists are community residents who manage the network, while FOCUS relies on a collective effort between the university and local experts. Training programs are available to support the sustainability of these networks, provided by organizations like Association for Progressive Communications (APC) and the Internet Society (ISOC). However, the training often falls short in adequately preparing community members for network operation and troubleshooting. Technical training poses challenges for local experts, including diagnosing network failures, managing users and devices, funding issues, technical knowledge, power disruptions, and adverse weather conditions affecting network setup. The FOCUS network requires on-site experts for immediate assistance during failures, while Janastu needs help with user and device management through a network management interface. Both networks face power-related failures and require funding for expansion, repairs, and infrastructure redesign. Additionally, adverse weather conditions can interfere with network equipment such as antennas.

3 METHODS

This research project took place between November 2021 and June 2022. During that period, we conducted 3 phases of research combining interviews with 6 co-design workshops to explore further their needs and challenges as well as design a network management interface with local stakeholders of Janastu and Focus CWNs.

3.1 Participating CWNs

The first phase of this research entailed interviews with network managers from six CWNs: Focus Network, Mamaila Community Network, Soweto Wireless User Group and VNET in South Africa, and Janastu and Maya Health in India. We recruited these 15 participants via snowball sampling through our personal networks. We continued recruiting until we achieved saturation in the responses from the participants [24, 25]. Later workshops were conducted in the communities of the three CWNs with which we have direct involvement, with a goal of deeper and focused enquiry

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

Table 1. This table shows the number of our participants from South Africa and India throughout the data collection phases

towards identification of phenomena: Focus Network in South Africa, Janastu in India, and Maya Health in India. Table 1 details the participants in each phase and Section 3.1 gives more details on each CWN, based on the interviews we conducted in Phase 1.

3.1.1 Focus 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.

3.1.2 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). Janastu[1] is a software non profit organisation from Bengaluru in India that operates a community network in

[1]https://www.apc.org/en/user/1715/

Durgadahalli village in South India. Janastu was formed in 2002 by Servelots as a collective and non-profit organization that focussed on supporting other communities and non-profit organizations with their needs. Since 2004 Servelots and Janastu have started working on WiFi mesh networks with volunteers and local community members to set up wireless mesh networks.

3.1.3 Maya Health COWHKI (Channapattna, India). Movement for Alternatives and Youth Awareness (MAYA) is a Karnataka-based non-profit organization established in 1991. MAYA health addresses social 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 Wireless Health Knowledge Infrastructure (COWHKI) project found athttps://mayahealth.net/.

3.1.4 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.

3.1.5 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.

3.1.6 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 Town[2].

3.2 Phase 1: Understanding Community Perspectives

The interviews aimed to understand community wireless network management from a non-expert perspective, as well as to identify challenges. First, we wanted to learn about the participants' backgrounds and how they had been involved in wireless networks technical training before being associated with their CWN or network management. Second, we also asked our participants to discuss their experiences with existing network management interfaces and how they used those platforms. Third, we 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. In addition, we also found out which network management interfaces existing community wireless networks share. We sent research consent forms to our participants via WhatsApp or email, depending on their preference. For 20 to 35 minutes, we conducted online interviews using video conferencing applications such as Zoom, Teams, and WhatsApp.

[2]https://vnet.vpuu.org.za/

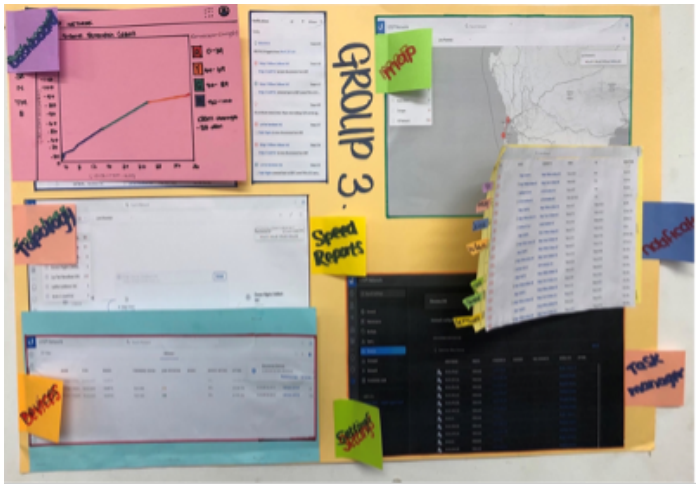

Fig. 1. A Network Management interface co-designed by participants

3.3 Phase 2: Co-Designing Network Management Interfaces

To follow up on the interviews and further understand our participants' challenges and experiences, we also conducted workshops with our two partner sites in Ocean View, South Africa and Devraynadurga, India: See details in Table 1 under phase 2. We intended to educate participants to network management through workshops by first examining their comprehension, attitudes perspectives on network management, and current CWN management practices. For Ocean View, we divided the participants into three groups and guided them through a video we created that went over the Unifi Network Management application that Focus CWN was utilizing. In the video, we demonstrated to the participants the various aspects of the Ubiquiti Internet Service Provider (UISP) platform, such as the landing page, the dashboard, and where to find more information.

3.4 Phase 3: Prototype demonstration Workshops

We started the workshops by revisiting the idea of network management in each site with our participants and recalling some outstanding outcomes from the first focus group discussions and co-design workshops. See details in Table 1 under phase 3. We then proceeded to introduce participants to (Radius Desk) Mesh Desk. In this activity, we 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/have a discussion.

3.5 Asynchronous Feedback

We collected asynchronous feedback from some participants two weeks after the prototype demonstration workshops. We requested feedback from the RadiusDesk(Mesh desk) demonstration regarding the challenges they encountered while using the radius desk independently and how many times they used it. The feedback's purpose was to track

participants' interest and engagement and to motivate changes we could make to the interface. For the asynchronous feedback, we only requested it from six prospective and local network operators from Janastu and Inethi/Focus.

3.6 Data Analysis

The authors conducted data analysis at the end of the project by identifying and exploring emerging themes from interviews and workshops. As a team, we met in Bengaluru (Bangalore), India, to conduct an initial analysis together, which started with transcribing the interviews and the workshop recordings. Our data collection produced 13 hours of recording from 4 workshops and 25 interviews. We conducted a thematic analysis by first reading through the transcripts from the interviews and highlighting the themes as they developed [10, 14]. After grouping all the similar themes, we compared them to the visual drawings and the themes from the workshop transcripts. We 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 envision network management.

4 FINDINGS: MANAGING CWNS IN PRACTICE

In this section, we provide findings on the network management challenges and the recent experiences of local and prospective network operators.

4.1 Mesh-mash: Hardware Diversity and Hardware Shortage in CWNs

From the initial interviews with 25 participants from Janastu, Focus, Mamaila, Soweto Wireless user group and VNET Khayelitsha community wireless networks, we talked about the current network setups, network management challenges and experiences of the local network and operators. In order to maintain and expand the network, operators must procure compatible equipment. At the time of this research, there was a worldwide shortage of AC Mesh routers, the most common mesh access point used for CWN deployments. Participants from South Africa and India complained that they could not access the equipment they wanted. Equipment readily available in other countries was much more challenging to acquire in the CWNs localities. For example, Janastu uses a combination of hardware from Libre Router, , Tp-Link and D-Link, acquired in 2004. Focus uses only routers - AC Mesh and Nanobeams. However, this hardware replaced Cambium routers which were mandated by a grant that funded the equipment for the network.

Both networks have a strong preference for wireless network devices. However, stock shortages have been a problem. When this is the case, the network operators turn to alternative devices. Hence the Janastu operators refer to their network as "Mesh Mash" [3], referring to the messiness of jury-rigging equipment from different manufacturers together in a single network. The jury-rigging equipment works partly because of the OpenWRT community's efforts to ensure their operating system is compatible with a wide range of devices from these manufacturers. However, updating the devices with the OpenWRT software requires technical skills or could result in severe equipment damage.

> "Right now, we are sticking with LibreMesh and TP-Link Routers. Their hardware limits us. The routers' supply chain limits us. The price point is also debatable. Then I started looking at alternatives." (I/P2)

Janastu and Focus prefer using Ubiquiti's wireless network devices, but during the time of this study these devices were not in stock, and local network operators were forced to purchase equipment from other manufacturers.

[3]Messy Meshes: Setting up at CowMesh at Devrayandurga. https://www.notion.so/Messy-Meshes-Setting-up-CowMesh-at-DDHills-42c5096ecb5f4dc4835f41cbe4bce429

4.2 Physically troubleshooting and Handling 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)

Our 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 [4] community network also shared their current network management practices; they have technical experts maintaining the network, and they are now familiar with the 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 interface. However, they illustrated that it gets better with experience, as the local network operator we interviewed has been managing the Soweto Wireless network since 2010.

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

The participants from Ocean View in South Africa outlined ideas on specific network management challenges that they experienced, for the features to become more user friendly. Participants suggested that 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 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, we 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.

> "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 we can know which access points are down at what time and attend to them immediately.(SA/P7)"

Janastu technicians faced the same challenges. However, since they possessed more technical experience, they were able to adapt an existing tool to their own needs.

> "But something interesting happened a month ago. We thought, why not build a network monitoring tool?" (I/P2)

[4] https://www.sowug.org.za/

5 DISCUSSION

This study emphasizes the need to consider the local knowledge and skills of local operators in designing network management interfaces to ensure the sustainability of community networks by local network operators and community members.

5.1 Mesh-Mash 2.0: Designing for Diverse Hardware

The growing complexity of network management tasks is a result of the continuous evolution of mobile network technologies, vertical integration, application heterogeneity, and the emergence of advanced end-user devices [23]. These factors necessitate the dynamic reconfiguration of networks to align with operators' cost and performance objectives [23]. 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 [5] argues that community networks need to self-organize themselves to address the community network challenges on the design, development and management of the network infrastructure as a shared resource to enhance community network sustainability [4]. However, our findings also indicate the need for increased expertise in utilizing 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 [11]. 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 visualization of current per-device usage [11].

5.2 Bridging Network-centered and Community-centered Models of Network Management

Network-centered models primarily focus on technical aspects such as infrastructure, protocols, and performance optimization, while community-centered models emphasize the social dynamics and collaborative practices within network communities. Recognizing the strengths of both approaches, researchers aim to bridge these models to enhance the effectiveness of network management [12]. To address the challenges associated with managing complex networks, Chetty et al. (2013) proposed a framework that combines network-centered and community-centered perspectives [12]. 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 [12]. However, Khan et al. (2018) proposed a multi-layer self-learning framework that enables self-network management and emphasizing the importance of leveraging data usage patterns of mobile users within community networks to gain a comprehensive understanding of community needs [23]. Hadzic et al. (2016) further support the utilization of mobile user data to inform community network requirements [21].Moreover, the involvement of users in the design process is crucial for developing acceptable systems. Winschiers et al. (2012) [42] and Bidwell (2011) [9] emphasized 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 [5, 8, 43].

5.3 Agenda for future designers

Agenda for future designers should be framed within a broader shift towards designing digital technologies that prioritize the public dimension of social life [39]. 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 surnrounding Software Defined Networking (SDN) [22]. The concept of autonomic network management is essential for equipping researchers with the understanding needed to address network management complexities [23].These findings underscore the need to prioritize 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 [38]. 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 [15]. Implementing automatic configuration models, where donors mesh with each other to aggregate internet access, can greatly benefit community networks [3]. Leveraging Multi-Path TCP (RFC 6824) enables the speed gains from access aggregation, and addressing, discovery, and routing challenges can be overcome through IPv4 and IPv6 solutions [3].

However, local network operators still require technical support, particularly in troubleshooting network issues [29]. Long-term sustainability relies on setting highly ambitious performance indicators for these systems [26]. Additionally, breakthroughs in physical layer technologies are crucial to overcome challenges posed by adverse radio propagation conditions in the mm wavelength range, enabling the usability of mobile wireless communications [26]. 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 [39]. Therefore, future designers should adopt a user-centric approach when designing network management platforms. Prioritize 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 emphasize the importance of incorporating autonomic network management principles [23]. Develop frameworks that enable self-learning and self-configuration to simplify network management tasks and reduce the reliance on manual troubleshooting [3, 44]. This will empower local network operators to efficiently monitor and troubleshoot their networks [44].

6 CONCLUSIONS

In conclusion, our study has contributed to a deeper understanding of the challenges encountered by local CWN operators and has emphasized the importance of adopting a community-centered approach to network management and design. By exploring the diverse equipment used by community networks, which often stems from the unavailability of standardized equipment, we have observed the use of various network management interfaces by these networks. This highlights the adaptability and resourcefulness of local operators in navigating the limitations they face. Furthermore, our research has underscored the significance of formal and informal training and learning opportunities for local network operators in effectively managing their networks. Recognizing 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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