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Title: Co-Designing Digital Connectivity: A User-Centered Approach to Wireless Community Networks in Low-Income Area

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Category	*Min*	*Max*	Chosen
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Co-Designing Digital Connectivity: A User-Centered Approach to Wireless Community Networks in Low-Income Areas

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Abstract

This research tackles the digital divide prevalent in South Africa, where high data costs and limited internet infrastructure disproportionately affect low-income communities. The project focuses on developing a mobile application for the iNethi Network, a community-driven wireless network in Ocean View, to promote digital inclusion. The application incorporates a map feature to visualize network coverage, track real-time data usage, and enable offline data caching, reducing dependence on costly internet connections. Employing a user-centered design approach, community members were actively involved in the co-design process to ensure the app meets their needs. Iterative development and usability testing revealed that user participation in the design process significantly enhanced the app's usability and user satisfaction. This study contributes valuable insights into ICT4D (Information and Communication Technology for Development), demonstrating that co-designed technological solutions can improve digital connectivity and service adoption in underserved communities.

CCS Concepts

• **Applied computing → Network management**; *E-government*; • **Human-centered computing → User centered design**; *Mobile computing*; Human computer interaction (HCI).

Keywords

Community Wireless Networks, Digital Inclusion, User-Centered Design, iNethi, Mobile Application Development, ICT4D, Co-Design, Usability Testing

1 Introduction

Internet usage and access to data in South Africa are severely limited by data caps imposed by Internet Service Providers (ISPs), coupled with high costs and unequal coverage [4]. These challenges are particularly acute in low-income areas, where the high cost of data relative to per capita income, combined with inconsistent mobile signal coverage, leads to low-quality connections [13, 20, 21]. The digital divide remains a significant global issue, with over 4.2 billion people still lacking internet access, representing approximately 58% of the global population [11]. In South Africa, prohibitively high data costs contribute to this divide, making internet access a luxury rather than a necessity, despite its crucial role in economic, educational, social, and cultural activities [23]. Marginalized groups, such as minorities, low-income individuals, and rural populations, are disproportionately affected by this lack of connectivity, further exacerbating existing disparities [11].

To address these challenges, Community Wireless Networks (CWNs) have emerged as a collaborative solution, providing shared telecommunication infrastructure for collective benefit [15]. However, current CWNs face limitations, such as the lack of nomadic broadband access, which requires users to find alternative means of connecting when not within network range [7]. These networks aim to bridge the digital divide by offering a decentralized and community-driven model for internet access, often using shared resources to reduce costs and improve coverage in underserved areas. One such initiative is the iNethi Network, led by the University of Cape Town (UCT), which has been deployed in the Ocean View community in Western Cape, South Africa. iNethi is a non-profit organization focused on ICT4D (Information and Communication Technology for Development) initiatives, aimed at establishing infrastructure that supports community-based services and content sharing. The organization's ethos revolves around empowering individuals in the creation, management, and cost-sharing of wireless networks. iNethi seeks to connect communities to the internet while also offering zero-rated local services, which do not count against users' data caps, thereby providing more equitable access to digital resources [3, 28].

Despite its potential, the iNethi Network faces challenges, particularly in bandwidth tracking and user engagement. According to Chetty et al. [4], users often have difficulty monitoring their bandwidth usage, which can lead to unexpected service interruptions when data caps are reached. Participants in their study reported that the primary indicator of being capped was the inability to browse or access non-South African websites. These findings suggest that iNethi users might face similar issues, including uncertainty about remaining data balances and unclear processes affecting their internet usage. In the digital age, users expect technology to integrate seamlessly into their daily lives, providing clear feedback on connection status and data usage [1, 18]. Therefore, for community networks like iNethi, offering a user-friendly experience while effectively managing bandwidth and connection stability is crucial.

Our goal is to develop an application that enables users to visualize their remaining data from the vouchers they have purchased for the iNethi app. Additionally, users will be able to track their connection status to the iNethi network and whether they have access to the internet. The application will include a service displaying the uptime and availability of local WiFi access points on a map, showing their distribution within the Ocean View community. This feature will enhance users' awareness of network accessibility. To further improve the user experience, the application will support offline content caching, reducing dependency on the network and alleviating network load by storing frequently accessed data locally [12]. Through these initiatives, we aim to encourage greater utilization of iNethi's resources and promote active engagement within the community.

2 Background

The digital divide, characterized by unequal access to digital technologies and the internet, remains a critical challenge in both developed and developing countries. This divide disproportionately affects low-income and marginalized communities, limiting their ability to participate in the global digital economy. In South Africa, high mobile data costs, unreliable infrastructure, and social inequalities further exacerbate the digital divide, preventing many from accessing vital online services such as education, healthcare, and employment resources [4, 11, 23]. The digital divide is not only a technological gap but also an economic and social one, where those without access are left behind in terms of opportunities for growth and participation.

2.1 Community Wireless Networks (CWNs)

In response to the growing digital divide, Community Wireless Networks (CWNs) have been established as a viable solution to provide affordable, decentralized internet access to underserved communities. CWNs are community-driven networks where the infrastructure is owned, maintained, and governed by local community members. These networks help bridge connectivity gaps by enabling local control over the network and reducing reliance on expensive commercial Internet Service Providers (ISPs) [16, 24]. In areas where traditional ISPs fail to provide affordable services or adequate coverage, CWNs play a crucial role in fostering digital inclusion [23].

Examples of successful CWN implementations include Guifi.net in Spain, which connects over 30,000 nodes and provides affordable access to the internet through community collaboration [24]. CWNs are particularly useful in low-income regions by reducing costs, enhancing coverage, and ensuring that the community can access necessary digital services and content at a much lower cost than conventional methods.

2.2 iNethi

iNethi is a non-profit organization led by the University of Cape Town (UCT) that focuses on ICT4D initiatives to support community-based services and content sharing. iNethi hosts various services, including educational content, local business information, and music sharing. The organization aims to empower individuals in creating, managing, and sharing the costs of wireless networks. One of its key deployments is in Ocean View, Western Cape, South Africa [3].

The Ocean View Community Wireless Network (OVCWN) is a community-owned mesh network that provides affordable access to local resources and the internet. The iNethi Network functions as a cloud platform at the network's edge, enabling content and service sharing within the community [14].

OVCWN currently operates 20 hotspots accessible to anyone within their range. The iNethi Network enhances digital participation, utilizes local resources, and promotes community cohesion. It also ensures data backup and remote access through synchronization with an Amazon Web Services instance. Community members can purchase data vouchers at R20 per GB, which is more affordable than the prices offered by mobile operators in South Africa [14, 29].

2.3 CWNs and Local Services

Applications within community networks (CNs) encourage participation by offering various services, including connectivity, communication, and entertainment. Some CNs focus on providing internet access, while others offer additional services like communication tools and entertainment [22]. Services that store or process data locally help maintain privacy by avoiding commercial data storage, as demonstrated by distributed cloud solutions like Cloudy in Guifi.net [17, 22].

Other services hosted on CWNs include crowdsourcing applications, which facilitate the exchange of information among community members, and VoIP services, allowing for low-cost communication using community-based internet access [17]. While internet access is often the main service, community networks can also provide local-interest services by leveraging cloud technologies to create community clouds, thus expanding the available services [26].

2.4 Addressing Usability and Accessibility through User-Centered Design

User-centered design (UCD) has emerged as a key approach in developing digital tools and services tailored for non-technical users, particularly in Community Wireless Networks (CWNs) deployed in low-income areas. UCD places a strong emphasis on designing systems that align with the actual needs, abilities, and behaviors of the users, ensuring that the final product is both usable and useful in real-world settings. In the context of CWNs, this design approach is especially important for communities with varying levels of digital literacy, where the interface must be intuitive and simple to navigate [19].

In South Africa, the iNethi network serves as a case study in UCD for CWNs. iNethi was designed with input from the Ocean View community in Cape Town, resulting in a mobile app that includes features such as real-time data usage tracking, visualized network coverage through maps, and offline content caching [2]. By involving the community in the design process, the network's features were tailored to user preferences, making the system more effective and enhancing user engagement. This highlights how UCD can lead to more sustainable community networks by fostering a sense of ownership among users [6].

An important consideration in UCD for CWNs is the issue of bandwidth management. Many users in low-income areas struggle to manage their data usage due to a lack of clear, real-time feedback on their consumption. Research indicates that users frequently experience service interruptions when they reach data caps without warning, underscoring the need for tools that provide clear indicators of bandwidth usage [5]. Simplifying the interface and making such data visible and easy to understand is essential for improving user satisfaction and network performance [20].

3 Related Work

3.1 Community Wireless Networks (CWNs) and Digital Inclusion

Community Wireless Networks (CWNs) offer a community-driven solution to the problem of digital exclusion, especially in underserved regions. These networks provide affordable, locally controlled internet access by leveraging community-owned infrastructure. Chetty et al. [5] describe how CWNs can reduce the cost of internet connectivity in low-income communities in South Africa by providing affordable alternatives to commercial ISPs. In a similar vein, Rodriguez et al. [24] discuss Guifi.net, a large-scale CWN in Spain that connects over 30,000 nodes, enabling affordable internet access through community collaboration. These studies emphasize the effectiveness of CWNs in bridging the digital divide.

However, while the technical and infrastructural aspects of CWNs are well-documented, less attention has been paid to how mobile applications integrated with CWNs can enhance user interaction and satisfaction. This gap is directly related to the first research question, which explores the impact of the iNethi app's map feature on users' ability to locate network nodes and monitor their connection status.

3.2 Data Usage Communication and Connection Status

Accurate communication of data usage and network connection status is vital for users, particularly in regions where data is expensive or where connection reliability is poor. Phokeer et al. [20] explore mobile data usage in South African township communities, noting the challenges users face in understanding their data consumption. Effective communication strategies are essential in mobile applications like iNethi, where users need to monitor their data usage and connection status to make informed decisions about their connectivity.

While some research explores offline caching and intermittent connectivity in community networks [9], there is a lack of studies focused on the best ways to visually or textually communicate data usage and connection status. This gap in the literature aligns with the third research question, which aims to identify the most effective methods for communicating data usage and connection status in the iNethi app.

3.3 Gaps in Existing Research

While existing literature provides valuable insights into Community Wireless Networks (CWNs) and the technical and economic benefits they bring to underserved areas, several important gaps remain:

- **Mobile Applications and CWNs:** Although CWNs have been shown to successfully bridge the digital divide, there is limited research on how mobile applications integrated with these networks influence user interaction and satisfaction. In particular, the effectiveness of tools such as map features for locating network nodes and visualizing connection statuses within community-driven mobile apps remains underexplored.
- **Usability and Design Elements:** Usability is a critical factor in ensuring the success of mobile applications, especially in contexts like community networks where users may have varied levels of digital literacy. However, there is a lack of research into which specific design elements, such as user interface components, are most effective in enhancing satisfaction and engagement within applications tied to CWNs.
- **Communication of Data Usage and Connection Status:** Effective communication of data usage and network connection status is essential for maintaining user awareness, particularly in regions where data costs are high and internet reliability is low. While some studies explore offline caching or the limitations of data access in low-connectivity regions, there is a scarcity of research that investigates the most effective methods of conveying real-time data usage and connection status to users in CWN-related mobile applications.

By addressing these gaps, this study aims to contribute to the understanding of mobile application design and usability within the context of CWNs, offering insights into how digital tools can be leveraged to improve user interaction, communication, and satisfaction within community-driven networks.

4 Research Aims

This research focuses on the co-design and iterative development of a mobile application for the iNethi Network, aimed at enhancing digital connectivity for the Ocean View community. The app is central to improving user interaction with the community wireless network, enabling users to monitor data usage, visualize network node locations, and better understand their connection status.

To achieve this, the research will address the following key questions:

(1) How did the introduction of the Map feature impact Ocean View community members' ability to locate network nodes and better understand the iNethi hotspots?
(2) Which design elements effectively enhance user satisfaction and usability in the iNethi app?
(3) What visual or textual methods are most effective for communicating data usage and connection status in the iNethi app?

By focusing on these areas, the research aims to improve the app's usability, ensuring it aligns with the needs and preferences of the community while addressing gaps in digital literacy and connectivity management.

5 Methodology

The experiment aimed to iteratively develop, test, and refine the iNethi app with the active participation of the Ocean View community. In this study we adopted a participatory co-design approach which is seen to democratize design to involve communities towards creating sustainable and context-appropriate innovations to their problems [27].

5.1 Ethical Considerations and Community Involvement

Before any interaction with the community, the research team obtained ethics clearance from the University of Cape Town (UCT) Faculty of Science. Research Ethics Committee (FSREC)This research adhered to ethical practices, guided by the TRUST Code for equitable research partnerships [28], focusing on fairness, respect, care, honesty, and transparency. Participants were provided with consent forms before each workshop, ensuring they were informed of the purpose of the research, what information was being collected, and their right to withdraw at any time.

Participants were informed whenever specific metrics were tracked (e.g., clicks or session duration) and were given the option to opt out of certain features or participation. All data was anonymized, and privacy was respected throughout. Information collected was stored securely, and no personal identifiers were used. Inclusivity was maintained by engaging a diverse group of participants, ensuring clear explanations of technical aspects to all. Ethical standards were upheld throughout, aligning with the principles of the TRUST Code.

5.2 System Development and Implementation

The iNethi app was developed to address the digital connectivity challenges of the Ocean View community, focusing on limited internet access and high data costs. Agile methodology guided the project development, with feedback collected from community co-design workshops to iteratively refine the app. Git and GitHub were used for version control to ensure efficient collaboration and code management.

5.3 Agile Development Approach and Co-Design Workshops

The development process was organized into four sprints, each focusing on specific objectives to enhance functionality and usability. Co-design workshops were conducted at the end of each sprint to gather feedback and guide further development. The feedback from these workshops directly informed each subsequent iteration.

5.4 Sprint Overview and Iterations

The development of the iNethi app was organized into four sprints. Each sprint had specific objectives focused on enhancing functionality and usability based on feedback from co-design workshops with the community. The details of the key objectives, deliverables, and outcomes of each sprint are provided in Appendix C (Table 7).

5.4.1 Sprint 1: Initial Prototype (Wireframe and Basic Features) Sprint 1 focused on establishing the basic structure for the iNethi app. A static map of iNethi hotspots was developed, along with user authentication using Keycloak to ensure secure login.

Key Features Developed:

- Static map of iNethi hotspots.
- Keycloak-based user authentication.

Outcome: Feedback from the co-design workshop indicated a desire for real-time network status updates and more interactive features. These requests shaped the focus of Sprint 2.

5.4.2 Sprint 2: Dynamic Map and Offline Caching In Sprint 2, dynamic features were introduced to the app. The static map was upgraded using Mapbox to show real-time status updates for network nodes, and offline caching was implemented to reduce data usage by storing map data locally.

Key Features Developed:

- Real-time network node status with Mapbox integration.
- Offline caching for map data.

Outcome: Although the dynamic map was well received, feedback from the second workshop indicated the need for clearer visual indicators for connection status. This feedback guided the next sprint's focus.

5.4.3 Sprint 3: Data Usage Tracking and Usability Enhancements Sprint 3 focused on improving the user interface and adding features for tracking data usage. A progress bar was implemented to visually represent users' remaining data. Amplitude and Google Analytics SDK were integrated to track user behavior and app interactions.

Key Features Developed:

- Data usage tracking with a progress bar.
- UI refinements for improved clarity and usability.
- Integration of Amplitude and Google Analytics SDK for tracking usage.

Outcome: Usability improved significantly, particularly for users with limited digital literacy. However, some users continued to struggle with distinguishing between local network connectivity and broader internet access, which led to further refinements in Sprint 4.

5.4.4 Sprint 4: Final Refinements and Full Deployment The final sprint involved refining the connection status indicator to clearly differentiate between local iNethi network connectivity and internet access. Bugs were resolved, and the app was optimized for deployment. Post-launch analytics tracking was enabled to monitor user engagement.

Key Features Developed:

- Refined connection status indicators for distinguishing between local and internet connectivity.
- Final bug fixes and performance optimizations.
- Post-launch analytics tracking using Amplitude and Google Analytics.

Outcome: The final version of the app was successfully deployed. All major concerns raised by users were addressed, and the app was well received by the community.

6 System Architecture

The iNethi system architecture is designed to provide a robust, scalable, and secure platform for community network management.

The architecture consists of three primary layers: the front-end mobile application, the backend server, and third-party services.

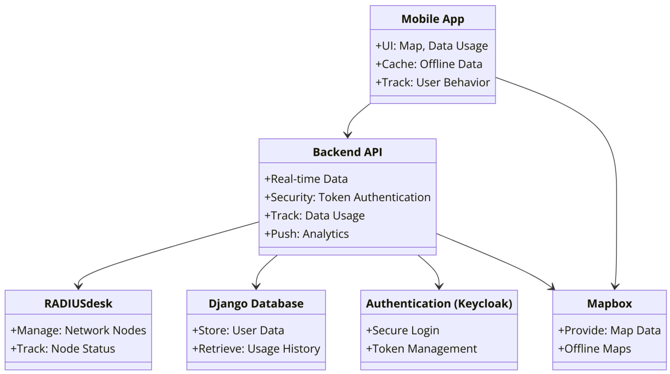

Figure 1: System Architecture of the iNethi Application

6.1 Front-End Infrastructure and Offline Caching

The front-end of the iNethi application was developed using React Native, with the integration of Mapbox GL for displaying network nodes on an interactive map. To ensure smooth user experience, especially in environments with limited internet connectivity, offline caching was implemented on the front end. This allowed the app to store critical data, such as map tiles and network node statuses, locally on the device.

Offline caching played a vital role in reducing data usage, as map data and network status information were stored and updated when the device was online. Users could access the map and view node statuses even without an active internet connection. Mapbox's offline capabilities enabled users to download map tiles, ensuring uninterrupted access to essential services within the app.

6.2 Backend Infrastructure and Security

The backend architecture of the iNethi application was developed using Django, an open-source web framework that supports rapid development and secure, scalable backends. The backend was designed and implemented by Erik Polzin, whose primary focus was creating a network management application for iNethi network managers. This backend provided real-time network status updates, user data tracking, and node management functionalities, making it integral to both the iNethi app and the web-based management system.

The backend architecture leverages a RESTful API, providing real-time communication between the mobile app and the backend server. It is closely integrated with RADIUSdesk for managing network nodes, which is responsible for handling node-related operations such as authentication and node status tracking. Additionally, Keycloak was employed for secure user authentication, utilizing token-based authorization to ensure only authorized users access network resources.

The backend enables real-time status updates for network nodes, as well as secure management of user data, including tracking individual data usage and interactions with network nodes. Django, in conjunction with RADIUSdesk and Keycloak, ensured that security protocols were robust and scalable, accommodating the needs of the iNethi network.

Key Front-End Features:

- Integration with Mapbox GL for interactive maps.
- Offline caching for map data and node statuses.
- Real-time updates when an internet connection is available.

This front-end architecture, combined with the backend's real-time data capabilities, allowed for a seamless and responsive user experience even in low-bandwidth or offline conditions.

6.3 Routing Algorithm for Nearest Node

The iNethi app implemented a routing feature to direct users to their nearest online hotspot. The Mapbox Directions API was used to calculate optimal walking routes between the user's location and the nearest active node.

Steps in the Routing Algorithm:

- Ping each node's IP to check for online status.
- Calculate the distance between the user's GPS location and the online nodes using the Haversine formula.
- Select the nearest node based on the shortest calculated distance.
- Display the route using the Mapbox Directions API.

6.4 User Tracking and Analytics

To monitor user engagement and gather insights for further development, the app integrated Amplitude and Google Analytics SDK. These tools tracked how users interacted with different features, how long they used the app, and which functionalities were most popular.

Key Metrics Tracked:

- Number of clicks on the map feature.
- Session duration (time spent using the app).
- Data usage tracking behavior via the progress bar.
- Navigation patterns to assess how users moved between app features.

6.5 User Involvement and Co-Design Approach

The involvement of the Ocean View community throughout the development process was crucial for ensuring the app's success. Feedback was gathered during workshops at the end of each sprint, allowing the app's features to be tailored to the specific needs of the community. This participatory approach ensured that the app was both practical and user-friendly, particularly for users with limited digital literacy.

Key Community Contributions:

- Feedback on map usability and connection status indicators.

- Suggestions for offline functionality and data tracking improvements.
- Input on simplifying the user interface for easier navigation.

6.6 Testing and Version Control

The app was rigorously tested at the end of each sprint. Usability testing was conducted during the workshops to gather feedback on specific features. Key areas tested included navigation, interaction with the map, offline functionality, and the clarity of connection status indicators. Version control was handled through Git and GitHub, ensuring that all changes were tracked and team collaboration remained smooth.

Testing Areas:

- Map feature navigation and interaction.
- Clarity of data usage tracking with the progress bar.
- Performance of offline functionality and data caching.
- Connection status feedback and clarity.

This structured and iterative approach, combined with community feedback and technical refinements, allowed the iNethi app to meet both technical and user-centered requirements.

6.7 Workshops Overview

Three workshops were conducted due to limited time, as ethics clearance took over a month before the workshops could be held. Each workshop had a specific purpose and was done in a sequential order to address different stages of the app's development, aligning with the research objectives.

Method of Engagement	Number of Participants	Date Completed
Initial Prototype Creation (01-June-2024)		
Figma Design Completed (15-June-2024)		
Workshop 1	13	09-August-2024
Analytics Integration (11-08-2024)		
User Iterated UI Created (12-August-2024)		
Workshop 2	15	13-August-2024
Final Design Implementation (15-08-2024)		
Workshop 3	19	20-August-2024
APK Released to Participants (21-August-2024)		
Post-Workshop Data Collection (22-08-2024 to 09-09-2024)		

Table 1: Participant Engagement Timeline and Key Development Milestones

6.7.1 Workshop 1: Initial Feedback and Prototype Introduction The first workshop was designed to introduce the initial prototype to users and gather their feedback on how they interacted with key features like the map displaying network nodes, data usage tracking, and connection status. This was done first to establish a baseline understanding of user needs and how they engaged with the features, allowing us to identify any immediate usability issues. It was essential to start here to inform the subsequent refinement stages, directly contributing to improving user interaction with network features, especially relevant to **Research Question 1**.

6.7.2 Workshop 2: Usability Testing and Refinements The second workshop followed up on the feedback gathered in Workshop 1 by testing the refined app. This step was necessary to evaluate whether the changes made to the app improved usability, particularly in terms of navigation, understanding node status, and tracking data usage. The order ensured that user-driven insights were directly applied to enhance the app before final evaluation. This workshop focused on ensuring the refinements aligned with user expectations and addressed **Research Questions 2** and **3** by simplifying technical information and improving overall satisfaction.

6.7.3 Workshop 3: Final Evaluation and Community Engagement The final workshop was done last to validate the fully developed app with the community, ensuring that the improvements made after the first two workshops effectively addressed the identified challenges. This order allowed us to test the complete, polished version of the app, ensuring the final evaluation was based on a mature, well-refined product. The focus here was on confirming that the app met user needs, particularly in understanding connectivity and data usage, addressing **Research Questions 1** and **3**.

6.8 Participants and Participant Selection

The recruitment of participants was spearheaded by Ganief Manuel, the CWN Manager overseeing iNethi in Ocean View and CEO of Black Equations, a key partner in supporting iNethi's operations. Ganief's involvement was crucial because of his established presence in the community, making it easier to recruit participants who were both familiar with the iNethi network and those who had limited exposure to digital technology. His role ensured a balanced mix of participants, drawing from various user groups within the community.To acknowledge their contributions to this project, the following participants requested to be recognized by their preferred names in this paper: Ralph Higgins, Jeniffer Pain, Theodere Groepies, Diego Kill, Tariq Adams, Leagan Parker, Spenser Muhammed, and Warren Mususa. Other participants preferred to remain anonymous and did not wish to have their names mentioned.

The workshops saw different levels of participation, starting with 13 participants in the first workshop, 15 in the second, and 19 in the third. Some participants returned for multiple workshops, bringing along friends to expand the group, resulting in a snowball sampling effect. This method helped reach a diverse range of users, from those more experienced with iNethi to others with little digital familiarity. This approach allowed for gathering comprehensive insights into the usability and design of the iNethi app, ensuring feedback reflected the varied needs and challenges within the community.

6.9 Workshop 1: Co-Design and Initial Feedback

The first workshop, conducted over a three-hour session at Ocean View Secondary School in collaboration with Black Equations INC, aimed to engage the Ocean View community in the co-design process of the iNethi app. The primary goal was to gather feedback from community members on features they found valuable and identify improvements. Key features included the map displaying the distribution of hotspots in Ocean View, a connection status indicator, and a feature for tracking data usage.

Thirteen participants, representing a cross-section of the community, attended the workshop. Participants included regular iNethi users and individuals new to the platform. The workshop began with an introduction to the iNethi project, its objectives, and the challenges it aimed to solve, such as improving digital connectivity and access to local online resources. For those unfamiliar with iNethi, this introduction was critical for setting the context and explaining the app's potential benefits.

6.10 Interface Comparison

Participants were presented with two interfaces for comparison:

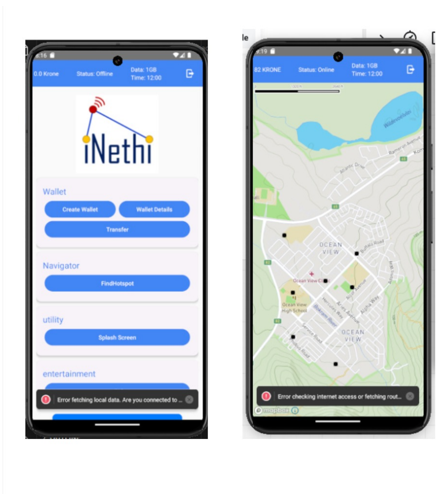

Figure 2: First Prototype of the iNethi App

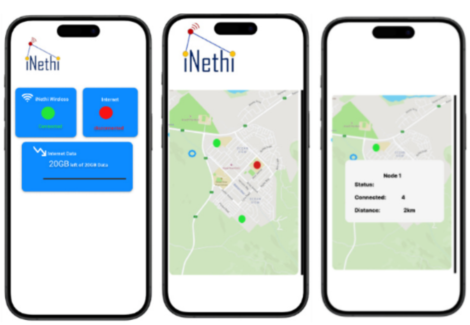

Figure 3: Figma Design of the iNethi App

- **Current Interface:** This was the existing version of the iNethi app, which included a map showing the locations of iNethi hotspots, along with features for monitoring bandwidth usage and connection status. It served as a baseline for evaluating the app's current functionality (Figure 2).
- **Proposed Interface:** This wireframe presented suggested improvements aimed at enhancing usability. The changes included color-coded markers to indicate whether hotspots were online or offline, more intuitive displays for tracking bandwidth usage (e.g., progress bars), and a clearer connection status indicator differentiating between being connected to iNethi without internet access and being fully connected (Figure 3).

The reason for showing two interfaces was to provide participants with a clear point of comparison, allowing them to assess the usability of the current design against the proposed enhancements. This helped determine which elements were more intuitive and aligned with their needs. The comparison was crucial for gathering detailed feedback on how users interacted with both designs and identifying areas for improvement.

Participants were encouraged to provide feedback on which interface they found more effective in facilitating their interaction with the app. This direct comparison allowed participants to visualize improvements and consider how the proposed changes could enhance their daily use of the iNethi app.

6.10.1 Focus Groups and Feedback Following the interface comparison, participants were divided into focus groups to discuss their experiences and provide detailed feedback. These discussions allowed participants to express their preferences, identify key features they valued, and suggest additional improvements. Notes were taken on key points raised during the discussions to capture ideas and concerns. This feedback was crucial for understanding user preferences, identifying potential usability issues, and gathering a range of insights into how the app could be improved.

The feedback collected during this session was instrumental in shaping the next steps of app development, ensuring that the iNethi app evolved in alignment with the community's needs and expectations.

6.10.2 Co-Design Activity Participants were also encouraged to engage in a co-design activity where they could either draw their ideal version of the app interface or list the features they would like to see. This activity allowed participants to visually express their ideas and preferences for the app's design. After sharing their designs, participants discussed and collaborated on refining their ideas into a more cohesive interface. This hands-on activity further emphasized the co-design approach, ensuring that the app would meet user needs based on their direct input (see Appendix 9).

6.11 Workshop 2: Usability Testing and Iterative Improvements

Workshop 2, held four days after the first workshop, aimed to test the updated version of the iNethi app and gather feedback on usability. Fifteen participants attended this 3-hour session at the offices of Black Equations INC. The focus was to ensure that users could navigate the updated app and understand technical information more clearly, particularly addressing any complex jargon.

6.11.1 Pre-Workshop Setup A WhatsApp group was created to distribute the updated app APK since it was not available on Google Play. Participants installed the app on their devices before the workshop, and technical support was provided to resolve any installation issues. One user faced compatibility issues due to an older Android device.

6.11.2 Usability Testing During Workshop 2, participants were asked to perform various tasks to test the app's updated features, particularly the usability of the map and data tracking. These tasks included assessing node status, monitoring data usage, and verifying connection status.

For a detailed breakdown of each usability test, including task descriptions and outcomes, refer to Appendix B.

Participants engaged in cognitive walkthroughs, sharing their thought processes and any challenges encountered. This provided valuable insights into the usability of the updated features.

6.11.3 Data Tracking Participants were informed that they could continue using the app after the workshop.These metrics helped assess user interaction with the app during and after the workshop.

6.11.4 Focus Groups and Feedback After usability testing, participants were organized into focus groups to discuss their experiences. The discussions aimed to simplify technical information for users:

- **Understanding Technical Jargon:** Feedback was gathered on how to simplify terms like node status and bandwidth usage.
- **Visual and Textual Representation of Bandwidth:** Participants discussed visual aids like progress bars to better represent data usage.

6.11.5 Tracking Engagement Participants were informed they could continue using the app after the workshop. The app's tracking feature monitored engagement post-workshop to assess which features were most useful and frequently interacted with.

6.12 Workshop 3: Final Testing and Community Engagement

The final workshop was held a week after Workshop 2 at Ocean View Secondary School with 20 participants. The goal was to test the fully developed iNethi app in a real-world setting, gather final feedback, and make any necessary refinements. Prior to the workshop, the app had been tested using Nielsen's 10 Heuristics to ensure it met usability standards and was accessible to non-technical users.

6.12.1 Installation Challenges and Technical Obstacles One of the primary tasks was for participants to install the final APK of the app on their phones via the WhatsApp group created in Workshop 2. However, due to unreliable internet access in Ocean View, the APK could not be shared through WhatsApp during the workshop. Attempts to use *ShareIt* for file sharing were only partially successful, as many participants did not have the app installed. One participant was able to install the APK via USB, but most were unable to complete the installation during the session.

6.12.2 Usability Testing During the workshop, participants who managed to install the app were asked to interact with it and provide feedback. They assessed whether the app's final features met their expectations and suggested any additional improvements. This feedback was crucial for identifying any final adjustments needed before the app's full deployment.

6.12.3 Post-Workshop Actions After the workshop, the research team successfully shared the APK via WhatsApp once back at the University of Cape Town. This ensured that all participants could install the app after the session. The app was equipped with tracking features to monitor user interaction, such as which features were accessed and how much time was spent using them. This data helped determine the app's effectiveness and provided insights into user engagement even after the final workshop.

7 Data Analysis

The researcher analyzed data from the co-design workshops using open coding and inductive thematic analysis, identifying themes like improved data tracking, offline functionality, and clearer network status indicators, similar to the approach by Till et al. [27]. Affinity mapping was then used to prioritize these themes. Additionally, quantitative metrics, such as session duration and feature usage, were collected via Amplitude and Google Analytics. Both qualitative insights and quantitative data were combined to refine the app, leading to a final design that addressed user needs and enhanced usability.

8 Findings

The findings from this study, centered on the co-design and development of a mobile application for the iNethi network, highlight several key outcomes. The project addressed the challenge of digital inclusion in the Ocean View community by enhancing accessibility to the iNethi wireless network. The mobile app's design was informed by a user-centered design (UCD) approach, where community members actively participated in the development process, ensuring the app met their needs. This approach mirrors the principles outlined in UCD literature, which shows that involving users early in the design process leads to more effective, user-friendly systems [1, 4]. Key features of the final design included a real-time map of network nodes, data usage tracking through a progress bar, and offline caching capabilities (see Figure 4). These features were refined based on continuous feedback from participants during the workshops, demonstrating the value of participatory design in enhancing digital tools for low-income communities.

8.1 Impact of the Map Feature on Locating Network Nodes

The introduction of the map feature, which visualizes the distribution of iNethi network nodes, significantly improved users' ability to find hotspots and monitor their connection status. During the workshops, participants engaged frequently with this feature, indicating a high level of interaction with the "Find Hotspot" button and the map tool. This reflects findings in previous studies, such as those by Maccari and Lo Cigno [15], which demonstrated the importance of visual tools in enhancing user engagement within community networks.

One of the primary advantages of the map feature was its ability to function offline, which proved particularly useful for unemployed users who could not always afford mobile data.The final design of the application (see Figure 4) incorporated Offline caching, allowing users to access network information without an active internet connection, aligns with similar strategies in other community networks, where offline functionality has proven to be a critical feature for low-income areas [12, 20].

8.2 Improving Data Usage Tracking and Communication

A key issue identified during the co-design process was the difficulty users had in tracking their data usage. Initially, the app displayed ambiguous labels such as "Data: 1GB," which many users misinterpreted as their total data allocation rather than their remaining balance. This issue was addressed by redesigning the data tracking feature, renaming it "iNethi Voucher Balance," and adding a progress bar that provided a visual representation of the remaining data. Studies have shown that clear, intuitive representations of data usage are essential in mobile applications, particularly in environments where users are sensitive to data costs [4, 21]. These changes significantly improved user satisfaction, with several participants noting that they now understood how much data they had left at a glance.

Effective communication of data usage and network status is critical in environments where data is costly, and users need to make informed decisions about their connectivity [12, 13]. By providing real-time data tracking, the app helped users avoid unexpected service interruptions, which had been a significant issue in previous studies on community networks [4].

8.3 Addressing Connectivity Challenges

Another challenge addressed was the ambiguity in communicating users' connection status. Initially, the app used a "Status" label, which did not clearly differentiate between being connected to the local iNethi network and having full internet access. Many users expressed confusion when they had local network access but no internet connection. This feedback led to the development of a clearer, more intuitive interface that explicitly distinguished between local connectivity and internet access. This mirrors findings in similar studies, which emphasize the importance of clear feedback mechanisms in mobile applications for low-connectivity regions [4, 21].

9 Discussion

The iNethi app was developed to address digital connectivity challenges in Ocean View by improving user engagement with community wireless networks (CWNs). This co-design approach was aimed at creating a tool that would empower users to track data usage, locate hotspots, and engage with the network. However, despite the app's usability improvements, it did not achieve sustained engagement outside of structured workshop settings.

9.1 Restating Research Objectives and Context

The primary objective of this project was to improve digital inclusion in Ocean View through a user-centered mobile app designed in collaboration with the community. The goal was to provide a practical solution that allowed users to better manage their data usage, monitor network connectivity, and engage more actively with the CWN. These objectives were set against the backdrop of the ongoing digital divide in low-income communities. Despite achieving technical improvements in the app's usability, the assumption that these changes would lead to long-term user engagement was not realized.

9.2 Critical Evaluation of Findings

The findings showed a clear difference between user engagement during workshops and post-launch interaction. During the workshops, users actively engaged with the app, particularly the hotspot map and data tracking tool. However, after the workshops, user retention dropped to nearly zero. The average session time during the workshops was approximately 31 minutes, but this was not replicated in real-world usage. The failure of users to return after the initial workshop interactions indicates a disconnect between the app's functionality and the actual needs or motivations of the users.

9.2.1 Engagement Issues The initial assumption was that clearer visibility of network nodes and improved data usage tracking would naturally result in sustained engagement. This assumption was proven wrong, as post-launch data showed no significant interaction outside the workshop setting. This pattern has been observed in other CWN and ICT4D projects, where user adoption post-launch often decreases significantly without continuous incentives or relevance to daily life [16, 24]. It is possible that users did not find enough ongoing value in the app, or that external factors like inconsistent internet access, socio-economic conditions, or competing priorities limited their interaction [23, 25].

9.2.2 Feature Effectiveness The features that were improved during the co-design process—such as color-coded nodes indicating network status and the progress bar for data tracking—were well-received during testing. User feedback during the workshops led to these enhancements, and participants appreciated the real-time visibility into their data usage and connection status. Studies by Maccari and Lo Cigno [15], and Densmore et al. [6], show that such technical improvements enhance the user experience in CWNs. However, these technical improvements did not translate into long-term app use, suggesting that other factors, such as engagement incentives or deeper integration into daily routines, may be needed [12].

9.2.3 Failure to Translate into Long-Term Use While usability improvements were successfully implemented, they did not lead to sustained user adoption. Factors such as low digital literacy, the cost of mobile data, and the app's limited relevance to everyday activities in the community may have contributed to this. It appears that the ability to monitor data usage and access network maps was not compelling enough to keep users engaged after the workshops. This finding aligns with prior research that stresses the importance of addressing both technical and socio-economic challenges for sustained engagement in digital tools [21, 25].

9.3 Comparison with Literature

This outcome aligns with similar findings in ICT4D and CWN literature, where projects focusing on usability improvements often struggle to maintain engagement post-launch. Studies such as those by Chetty et al. [4] and Phokeer et al. [21] highlight the challenges of digital adoption in low-income areas, where the immediate needs of users often extend beyond the technical features provided by community-driven apps. The failure to sustain engagement despite a user-centered design process suggests a deeper disconnect between the app's capabilities and the community's broader socio-economic context, as discussed by Sambasivan et al. [25] in their work on technology adoption in urban slums.

9.4 Challenging Initial Assumptions

The initial assumption that improved usability and feature visibility would automatically result in higher user engagement was flawed. This project assumed that if users were able to easily track their data usage and network status, they would regularly interact with the app. However, this assumption did not account for the complexities of user behavior in low-income communities, where other factors, such as affordability of data and the relevance of the app to daily life, play a larger role in long-term engagement [10]. Studies such as those by Rey-Moreno et al. [23] emphasize the need for continuous user engagement strategies and addressing broader community needs beyond technical functionality.

9.5 Broader Implications

The broader implications of these findings highlight the complexity of creating digital tools for low-income communities. The failure of the iNethi app to drive sustained engagement suggests that, while usability improvements are necessary, they are not sufficient. Similar findings from Guifi.net [24] and community networks in South Africa [23] suggest that digital tools need to provide continuous value and align more closely with users' daily challenges and priorities. Future ICT4D projects must take into account the socio-economic conditions and daily realities of their target users, ensuring that the app provides ongoing, practical value that extends beyond mere technical enhancements.

9.6 Recommendations for Future Work

Based on the findings, several recommendations can be made for future work:

- **Deeper User Research:** Conduct ongoing qualitative research to better understand the daily digital needs and motivations of the community. Focus groups or interviews should explore why users did not return to the app and what additional features could provide more value. Other research has shown that deeper understanding of the community can significantly improve the relevance and engagement of such projects [7, 15].
- **Long-Term Engagement Strategies:** Introduce incentives for sustained engagement, such as rewards for regular app use or push notifications for low data balances. Engagement strategies should be tailored to the specific behaviors and needs of the community, as suggested in studies by Fernandes et al. [8].
- **Improving Connectivity Solutions:** The app could provide more proactive solutions for dealing with network outages, such as suggesting alternative hotspots or providing offline content that is more integrated with users' needs [8].
- **Expanding Offline Capabilities:** Expand offline functionality to include more relevant local services or content, which could keep users engaged even when they are not actively connected to the network. This has been shown to improve user retention in similar projects [12, 15].
- **Continuous Community Engagement:** Engagement should not end with the app launch. Ongoing workshops, updates, and direct involvement from the community in future development efforts are essential for maintaining interest [27].

9.7 Limitations and Reflections

The key limitation of this project was the controlled nature of the workshops, which may not reflect real-world user behavior. The reliance on analytics data to track engagement without conducting follow-up interviews or surveys also limited the ability to fully understand the reasons behind the low post-launch retention. Additionally, broader socio-economic factors, such as data costs and unreliable internet access, were not fully addressed in the app's design, which could have contributed to its limited adoption.

9.8 Conclusion

In conclusion, while the iNethi app succeeded in improving usability through a co-design process, it failed to achieve sustained engagement. The project highlights the importance of not only focusing on usability improvements but also understanding the broader context in which the app will be used. Future efforts should prioritize deeper community engagement, long-term user research, and features that address the practical realities of low-income communities. This project contributes to the ongoing discussion in ICT4D and CWNs on how to effectively bridge the digital divide in underserved regions.

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A Appendix: Figures and Artifacts

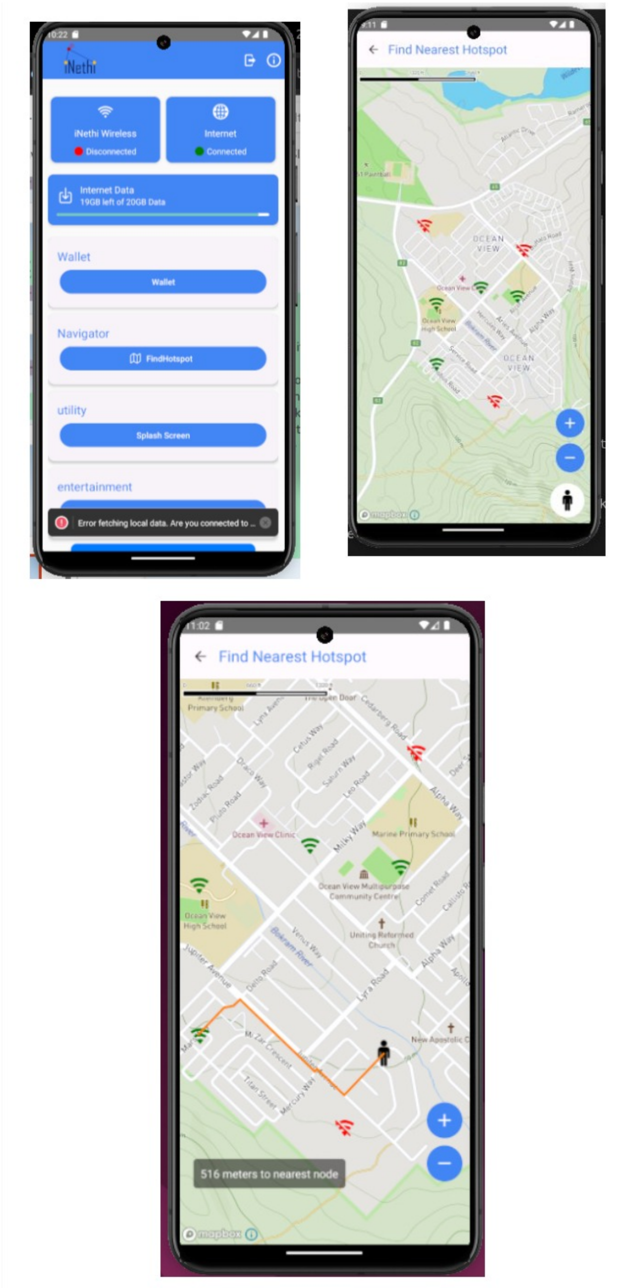


Figure 4: Final Design of the iNethi App

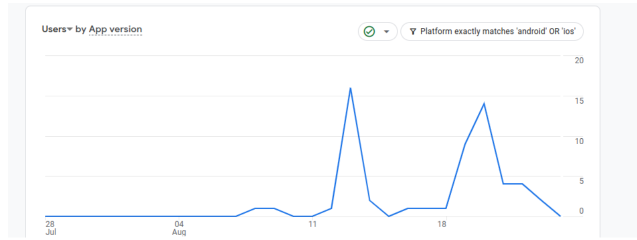


Figure 5: App Usage Statistics from Workshop Sessions

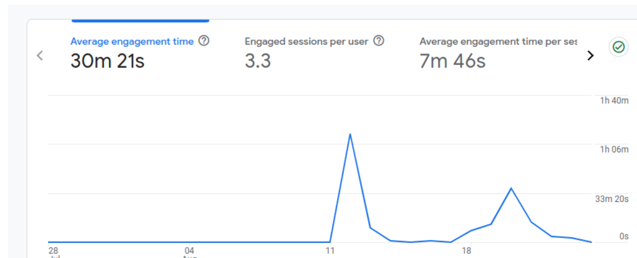
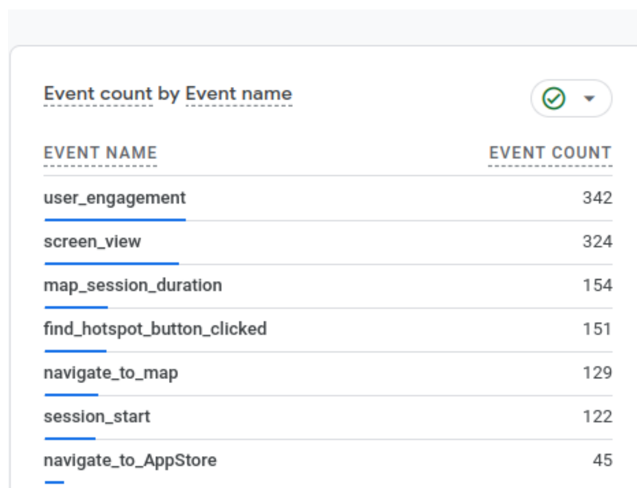


Figure 6: Average Session Duration During Workshops



Event count by Event name

EVENT NAME	EVENT COUNT
user_engagement	342
screen_view	324
map_session_duration	154
find_hotspot_button_clicked	151
navigate_to_map	129
session_start	122
navigate_to_AppStore	45

Figure 7: Clicks per Feature in the iNethi App

Figure 8: Retention Rates of iNethi App Post-Workshop

B Appendix: Usability Test Tables

TEST ID	1
Date	[13/08/2024]
Purpose	To evaluate the intuitiveness of the map feature and its ability to communicate node status effectively.
Instruction	Open the app and use the Map feature to locate the nearest online network node. Then, find an offline network node.
Expected Outcome	Participants should be able to identify and locate both online (green icon) and offline (red icon) network nodes using the map. They should do this with minimal confusion.
Actual Outcome	participants were able to easly find a node and tell it's status

Table 2: Evaluating the Map Feature's Impact on Locating Network Nodes

TEST ID	2
Date	[13/08/2024]
Purpose	TTo assess the clarity and effectiveness of the data usage display.
Instruction	Navigate to the data usage section and check your current data balance. Describe how much data you have left and interpret the usage bar.
Expected Outcome	Users should accurately understand their remaining data balance using the labels on the home screen
Actual Outcome	During testing, users initially misunderstood the "Data: 1GB" label, interpreting it as their total data allowance instead of their remaining balance. This confusion caused uncertainty about how much data they had left to use. They requested the label tp be changed to "iNethi Voucher Balance," and a progress bar to be added to see data usage more clearly.

Table 3: Track Data Usage

TEST ID	3
Date	[13/08/2024]
Purpose	To evaluate the offline functionality and usefulness of the cached map data.
Instruction	Simulate being offline by turning off your internet connection. Use the app to navigate the map and try to find the location of the nearest hotspot.
Expected Outcome	Users should be able to access the map and find hotspot locations even without an internet connection.
Actual Outcome	Users were able to successfully use the map feature to locate both online and offline network hotspots. The color-coded icons (green for online and red for offline) made it easy for users to distinguish the status of each hotspot at a glance. Participants found the map intuitive to navigate, and the ability to zoom in and out helped them view specific areas more clearly.

Table 4: Use the Offline Map Feature

TEST ID	4
Date	[13/08/2024]
Purpose	To test the clarity of the connection status indicator.
Instruction	Use the app to check your connection status. Determine if you are connected to the iNethi network with full internet access, limited access (only to whitelisted websites), or no access
Expected Outcome	Users should clearly understand their connection status without confusion.
Actual Outcome	Users struggled to understand what the "Status: Online" label indicated regarding their connection status. Many found this label ambiguous and spent time on the screen feeling confused, as it did not clearly communicate whether they were connected to the iNethi network, had full internet access, or were limited to whitelisted websites. Users expressed that the current label did not provide sufficient information to understand their connectivity situation. They suggested redesigning this section to include separate indicators: one to show the status of being connected to the iNethi network and another to indicate whether they had full internet access. This feedback highlighted the need for clearer, more specific information to help users quickly assess their connection status.

Table 5: Check Connection Status

TEST ID	5
Date	[Insert Date]
Purpose	To test the presentation of network performance data to ensure it is understandable and useful.
Instruction	Check the performance indicators for each hotspot, such as signal strength and speed. Describe what you observe.
Expected Outcome	Users should be able to interpret performance indicators and understand the quality of different hotspots.
Actual Outcome	Users found it challenging to interpret the network performance indicators. The terms used to describe signal strength and speed were unclear, leading to confusion about the quality of different hotspots. Several participants spent extended time trying to understand what the performance metrics meant and how they applied to their real-world internet experience. Users suggested that the network performance data should be represented in a more intuitive way, such as using easily recognizable icons or color codes (e.g., green for strong signal, yellow for moderate, red for weak) alongside simple textual descriptions. This feedback highlighted the need to redesign the network performance section to make it more user-friendly, ensuring that even non-technical users could quickly assess the quality of available hotspots.

Table 6: Understanding Network Performance

C Appendix C: Sprint Overview and Iterations

Table 7: Sprint Overview

Sprint	**Objective**	**Key Deliverables and Outcomes**
Sprint 1	Initial Prototype (Wireframe and Basic Features)	Developed a basic wireframe with a static map of iNethi hotspots and user authentication using Keycloak. Feedback focused on requests for dynamic features and real-time updates.
Sprint 2	Dynamic Map and Offline Caching	Integrated Mapbox for real-time network node statuses (online/offline) and introduced offline caching to minimize data usage. The community requested clearer visual indicators for connection status.
Sprint 3	Data Usage Tracking and UI Enhancements	Added data usage tracking with a progress bar, improved the user interface for clarity, and integrated Amplitude and Google Analytics SDK for tracking user behavior.
Sprint 4	Final Refinements and Full Deployment	Refined connection status indicators for clearer distinction between iNethi network and broader internet connectivity, resolved bugs, and finalized the app for deployment. Post-launch engagement tracked using Amplitude and Google Analytics.

D Appendix: Sketch

Received 20 February 2007; revised 12 March 2009; accepted 5 June 2009

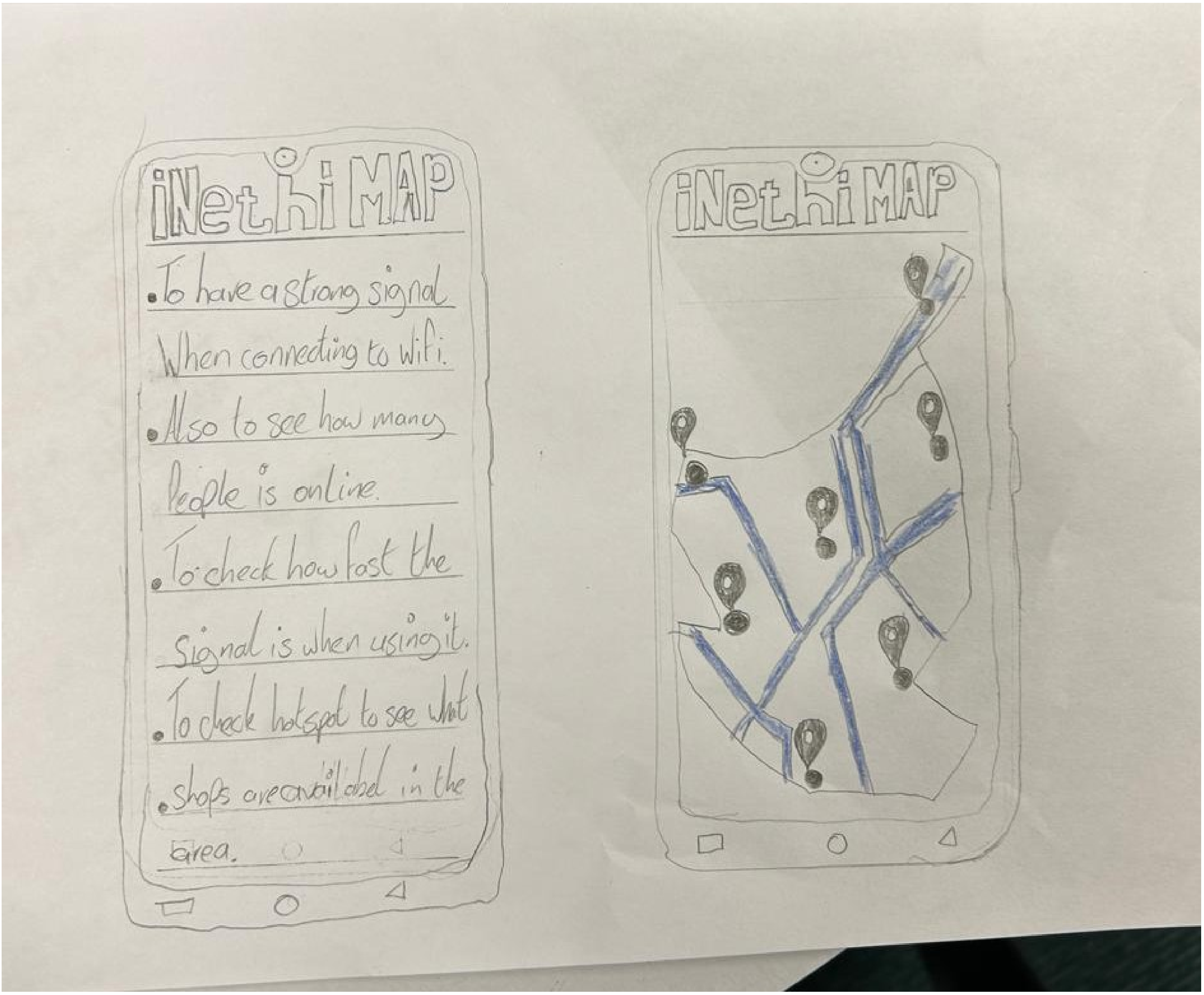


Figure 9: Sketch Created by Community Members