TownshipNet: A localized hybrid TVWS-WiFi and cloud services network

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***Abstract*—This paper describes a network architecture to provide low cost last mile access and cloud services for local content sharing in a poorly resourced township environment. We describe how ICT solutions are developed in close partnership with the local community who will benefit from the interventions. We analyze the data usage patterns of mobile users in the township to provide us with a real understanding of the needs of the community. This data usage analysis is used to inform the design of the network and of the localized cloudlet services. The network consists of hybrid TV White Space and WiFi backhaul and WiFi public access points.**

Keywords— wireless backhaul, ICT4D, TVWS, local content generation, cloud.

I. Introduction

Townships (a term used for urban informal settlements in South Africa) typically have limited connectivity options (mostly 3G), however even those are often limited due to lack of affordability for the average user. Devices for accessing the Internet are often restricted to mobile phones, and increasingly exclusively smart phones.

Much of the Internet traffic on these smart phones consists of application downloads or updates [1] as well as traffic between users in nearby proximity [2]. In general, social interactions are known to depend on geographic proximity, where friendship probability decays with distance [3]. This provides strong motivation for a new Internet architecture where local free/low-cost public WiFi is provided for commonly accessed content and localized services are used for content sharing between users who are living in close proximity.

Licence-free backhaul connectivity to connect public WiFi access points in poorly connected areas has traditionally used 5 GHz WiFi. In our architecture we make use of a hybrid of TV White Space and 5 GHz WiFi for wireless backhaul. TV White Space makes use of unused TV channels in specific geographic locations to provide connectivity. In our system we make use of radios that down-convert WiFi into the UHF band.

The use of localized cloudlets – small datacenters found at the edge of the Internet [4] can improve network performance and provide processing and storage capability at the network edge and also provide redundancy should the Internet backhaul link fail. Distributed Cloud services have also been provided in rural areas in the VillageShare project [2] and provide localized content sharing. We make use of these concepts in our TownshipNet network architecture in this paper.

Our trial site, where our TownshipNet architecture will be used is Masiphumelele, a township in Cape Town, South Africa, situated between Kommetjie, Capri Village and Noordhoek occupying roughly one square kilometer. We have selected this township due to the large number of NGOs working in health care, education and youth development and our hope is that TownshipNet will amplify the good work already happening in the township.

We can divide our contribution in three parts: (1) analyzing mobile phone usage patterns, (2) providing low cost last mile access, and (3) providing a local cloud for collaboratively generated content. By exploring the mobile data usage patterns we will be able to understand user needs and provide an appropriate solution to the community. The remainder of the paper is organized as follows: we describe the background and motivation in the next section, followed by a brief overview of related work in Section III. Our methodology and contributions are given in Section IV, and network architecture is illustrated in Section V. We present some of our preliminary results in Section VI. Finally, in Section VII we conclude the paper and describe our future work.

II. Background and Motivation

Masiphumelele, initially known as Site 5 during Apartheid in the 1980s, is a Xhosa word meaning "We will succeed". In 2010, the population was estimated at 38000. A number of NGOs such as Living Hope, MasiCorp and Desmond TuTu foundation have been working for the past decade to uplift the community through health care, education, youth programs and business development initiatives and there are many opportunities to develop ICT solutions to compliment these services. The township currently has no public WiFi and the City of Cape Town's planned public WiFi project in the townships of Khayelitsha and Mitchell's Plain will not be implemented in Masiphumelele in the short term.

Current Internet in Masiphumelele is limited to 3G from the biggest South African operators (Vodacom, MTN and Cell-C), an Internet Cafe and Internet access at the Library. We are

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currently deploying a hybrid TV white space and 5GHz WiFi long-range mesh to connect the township to the Internet and other townships. Within Masiphumelele, a shorter-range backhaul mesh also making use of both WiFi and TV white spaces will be used to connect the various hotspots around Masiphumelele to the local server at the project office (labelled on the map in Figure 1). The key purpose of this project office is to embed ICT researchers in a township environment in order to install a research culture where ICT solutions are developed in close partnership with community members. Initially the Public WiFi access points in Masiphumelele will only be used to access local content on the server in Masi. The long-range backhaul link will be used to synchronize this local content with global servers.

Figure 1: Project office within Masiphumelele township. Green lines represent TVWS/5GHz WiFi hybrid backhaul links are shown in green, yellow circles are 2.4 GHz WiFi hotspots.

In order to achieve a low-cost solution for last mile Internet connectivity, we supplement WiFi with TV white spaces [5]. We opt for TV white spaces as there are significant unused channels in the VHF and UHF bands historically assigned to television broadcasting services. The use of TV white spaces is particularly attractive in rural areas with poor connectivity as the UHF and VHF bands have far better propagation characteristics compared to the 2.4 GHz and 5 GHz bands used by WiFi [6]. Our initial spectrum scans have also revealed that this area in the deep south of Cape Town also has significant amounts of available unused TV spectrum.

Backhaul links will be formed using the TV white space mesh nodes (WSMN) developed at CSIR Meraka Institute over the past two years. WSMN is a multi-radio mesh with any combination of 2.4 / 5GHz WiFi and TV White Space radios. The nodes use the Doodle lab downconverted WiFi card. A typical WSMN is shown in Figure 2.

The WSMN is a scalable platform, and supports up to 5 radios with any combination of 2.4 / 5GHz WiFi, TV White Space radios or other future radios. The OpenWRT platform uses packages to add new features to web interface and backend processing. Multiple USB ports are available for USB-based radios or devices, as well as a Micro-SSD slot for up to 64 GB of storage (e.g. spectrum scan logs).

We managed to embed the following features into the White Space Mesh Node:

- Supports PAWS connection to Geo-Location Spectrum Database
- Built-in GPS to acquire position for spectrum database query
- Built in spectrum analyser for optimal clear channel selection
- Support for 5/10/20 MHz Channels on White Space links
- B.A.T.M.A.N. or OLSR mesh protocols on WiFi and TV White Space links
- Best path selection on WiFi or TV white space links
- Full IPv6 support with auto-IP configuration
- Support for multiple Internet gateways using tunnels.

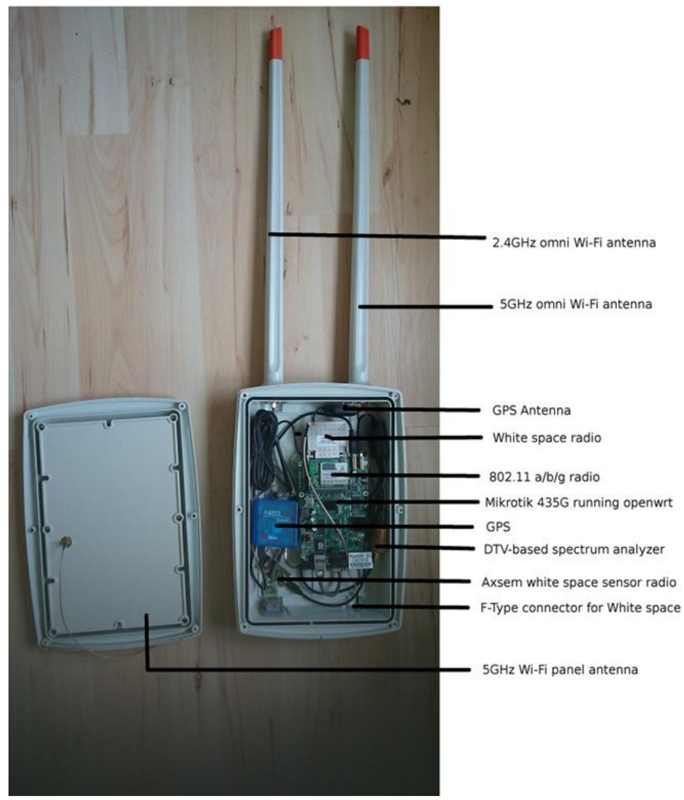

Figure 2: White Space Mesh Node developed ad CSIR

III. RELATED WORK

Low cost last mile connectivity usually relies on unlicensed bands such as 2.4 GHz and 5 GHz spectrum [7] and license exempt dynamic spectrum access, i.e., use of TV white spaces [5], [8]. However, smart channel allocation algorithms are needed to assure that interference is avoided [9]. Besides free spectrum usage, most technologies deployed so far use off-the shelf hardware for implementation, in order to keep the costs low. Most studies on adoption of cloud computing investigate the topic from a perspective of developed countries. However, there are specific challenges that need to be tackled when it comes to deploying cloud services in developing countries [10][11]. A hardware platform based on small single-board computers to roll out cloud-based services to rural and remote areas is presented in [12].

VillageShare [2] is a distributed system that increases content accessibility by hosting user-generated content in localized clouds closer to the users. Local VillageShare users upload and store media from their devices to their account on the local VillageShare content server using public wireless connectivity such as WiFi. This helps alleviate the limited storage capacity found on most phones and serves as a means for content sharing. Each user has a friends list with whom they can share uploaded content. VillageShare also synchronizes a local cloud to other localized clouds, and a global cloud to allow users to share content with users in other areas or for users who travel to have access to their content. We will build upon the VillageShare architecture in this work. Mathur et al. studied the mobile users' data usage practices in South Africa. They found that unlike in more developed regions, when data is capped or expensive, users tend to adopt a more cost-conscious approach to reduce the consumption of mobile data [13]. The authors used a mixed-method study by using the MySpeedTest app [14], a survey and a semi-structured interview, from which they triangulated the data collected to present statistics. Kang et al. collected real usage log of mobile phone usage over a period of two months. Data collected gave indication of the amount of time users spend on voice calls and data communications per access networks (3G, WiFi, etc.) [15]. Falaki et al. did some similar experiments on 255 users, they studied the user behaviours and measured the number of interactions and the amount of data received on the device [16].

IV. Methodology

We are utilizing novel state of the art wireless technologies for providing affordable last mile connectivity. This will be coupled with efficient edge caching and localization of content and services at the edge nodes to provide faster access to content and services. However, before starting with our network design, we first need to get some insight about the mobile Internet usage trends in Masiphumelele. Research outcome can be generalized to other places in Africa with similar demographics. The idea is to investigate how much traffic is being generated for social media, VoIP communications, messaging, software updates, video streaming, etc. Mobile Internet is available through different media: pay-as-you-go services (2G/3G/LTE), free public WiFi, paid Internet at Internet cafés, local free community wireless, zero-rated services from some providers [17].

We are trying to understand what are the characteristic ways in which mobile Internet enabled applications are used in the Masiphumelele township. In this sense, we need to find out how economic factors affect mobile data usage, and how the usage and Quality of Experience (QoE) is influenced by different connection medium. The experiment is two-fold: measurements with MySpeedTest application and a survey for qualitative data collection. The MySpeedTest is an Android mobile application developed by the GTNoise Lab at Georgia Tech [18]. The application was used in the study of broadband performance in South Africa [13][14]. The tool basically would allow us to measure the throughput, latency to known online services and data usage of different applications on the user's smartphone (Figure 3). There is also the feature to collect traceroute data to the location of choice. The application will also collect some metadata such as network operator's name, SSID, data cap plan and so on, which could also be used in the analysis.

Figure 3: MySpeedTest application interface

We use the application to gather data on network traffic. It will run on the candidate's mobile phone for a consecutive period of four weeks. Data collected are sent to a central database at Georgia Tech, which will be queried using SQL statements for data aggregation. Those measurements will allow us to get the average amount of data in MB transferred in and out by application, and the average amount of data in MB transferred in and out by connection type.

Data on behavioural aspects such as 'preferred applications' will be collected blindly via a survey form. The idea is to cross-verify behaviours of users collected from the measurement application as opposed to the responses received from the survey. Survey will be done using the Google forms application. Forms will be filled with responses from the participant, on the spot at the project office, by the researcher. The data collected will help us get information about the most preferred application, preferred network connection type, most preferred usage of mobile Internet services, amount of money spent monthly on data bundle/airtime, percentage of social media contacts within the same locality.

V. Network Architecture

The network architecture for backhaul and access will make use of blended connectivity. On the backhaul, a connection between different WSMNs is possible between 5 GHz Panel and Omni antennas and a connection is also possible between the TVWS Yagi antennas in the UHF band.

Access to devices is provided by the 2.4 GHz Omni antenna. Figure 4 shows all the permutations of connection options available.

The BATMAN mesh protocol is run on both 5 GHz radio interfaces and the TVWS radio and the best link (with the least amount of packet loss) will be chosen to route traffic. This configuration allows the WiFi to be used when good line-of-site links are available and the TVWS link to be used when there are obstructions such as trees in the path of the wireless link. Interference on either TVWS and WiFi can also be a factor that causes the mesh routing metric to choose a different link.

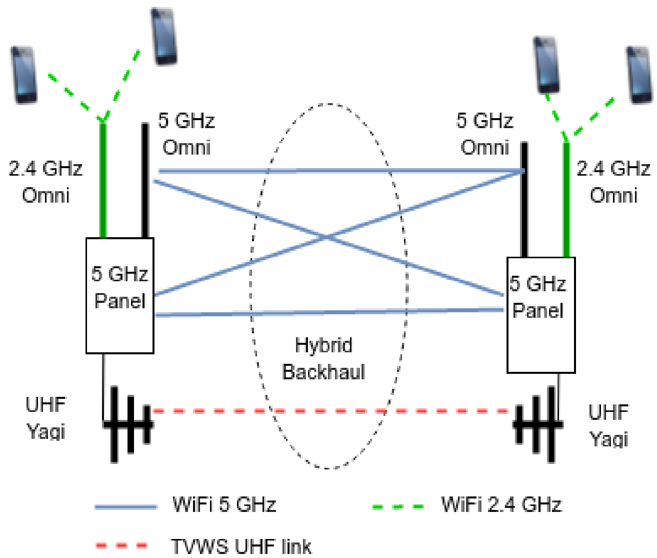

Figure 4: Wireless connectivity in TownshipNet between WSMNs

The TVWS/WiFi hybrid links will be used to synchronize the local township cloudlet to the global cloud. The local cloudlet architecture is shown in Figure 5. The Township cloudlet will make use of open-source cloud services such as OwnCloud for file sharing, Signal for local chat messaging and Diaspora for local social networking.

OwnCloud will allow users to store content on their phones in a local cloud within a limit (5GB in the current configuration). Many users report having no other devices to store content from their phones such as laptops, and services such as Dropbox are too expensive to use over costly 3G services. The Owncloud service also allows users to share content with other users in the township. Signal is a local chat app which can allow users to message each other for free. Diaspora is a local social networking application which allows users to build a local social network and share images and messages with each other. We plan on integrating these services so that users, for example, are notified on Diaspora or Signal about content being shared with them on Owncloud. We also plan to expand the service to other neighboring townships and the cloudlets will intelligently synchronize their content with other cloudlets when users share content between two different townships or when they travel between these townships. We will also synchronize some content to a global cloud for users that travel and want to access their content outside the townships while travelling.

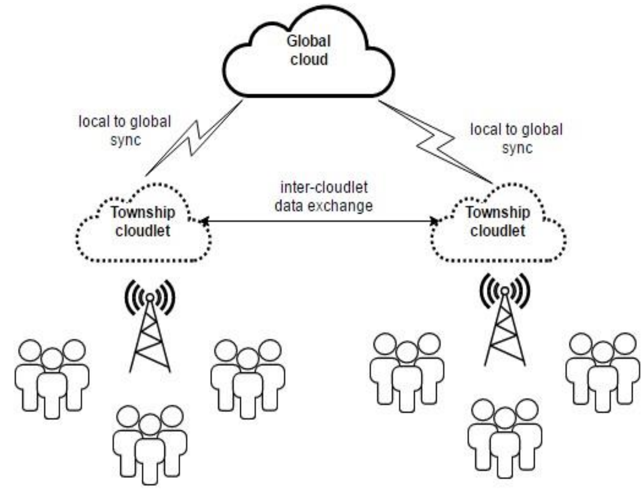

Figure 5: Local cloudlet architecture

Besides social media, a lot of Internet traffic is consumed for mobile applications update purposes. Therefore, we plan on making commonly accessed content such as application updates or new applications installations available from the local township cloudlets.

VI. Preliminary results from measurements

A. Current usage patterns on smart phones

In order to pre-test our measurement platform, we perform data collection for a set of four users during a period of five consecutive weeks. Obviously, the data set is too small to infer any statistics or usage pattern. However, we could observe that to a certain extent it corroborates with the findings of Mathur et al [13] in terms of most used applications (Table 1). The MySpeedTest application itself has been removed from the list.

Table 1: 10 most used applications

Application	**Total usage in MB**
Any Share*	423.31
Google Play Store	345.62
Facebook	70.78
WhatsApp	63.46
Administrator ctas	27.94
Chrome	15.46
Download Manager	13.37
Youtube	12.78
Google Search	6.47
Gmail	5.88

*Anyshare is a peer-to-peer file sharing application and does not require an Internet connection. In tables 2 and 3, we purposely removed it from the list.

In terms of WiFi (Table 2) vs. mobile data usage (Table 3), our measurements do not correspond to those of [13], where it was shown that in case of limited or expensive data plans, mobile Internet users are extremely cost-conscious, and employ different strategies to optimize data usage, e.g., actively disconnecting from the mobile Internet to save data. Our set of measurements shows that mobile data usage is greater than WiFi usage, which could be explained by a lack of WiFi facilities in townships.

Table 2: 10 most used applications over WiFi

Application	Total usage in MB
Facebook	24.04
Google Play Store	19.40
Chrome	15.46
Youtube	12.78
WhatsApp	10.55
Takealot	6.77
Bluetooth App Sender	5.97
Gmail	5.88
Instagram	2.46
Mobile Protect	2.40

Table 3: 10 most used applications using mobile data

Application	Total usage in MB
Google Play Store	325.00
WhatsApp	52.79
Facebook	45.75
Administrator ctas	27.90
Messenger	13.43
Download Manager	13.37
Google Play – Dienste	11.01
Meteo	8.60
Google Search	6.47
Blocco vocale	2.91

We found that a large amount of mobile data is used for applications update. Application updates are available on Google Play Store and smartphones are automatically synchronized to pull the latest updates. If we multiply the update action by thousands of phones in a community, we end up actually spending a huge amount of data doing the same task, i.e., by updating the same set of applications. The ultimate idea would be to find a solution that allows users to update their phones, without consuming Internet traffic itself. If we can predict the phone updates and provide those updates in a "localized" fashion, not only updates will be faster, but will also be less costly.

Social media platforms are the most popular applications. Facebook and WhatsApp top the list followed by YouTube, Gmail, and games. Preliminary survey results revealed that most of the interactions on social networks are targeted to users who reside relatively nearby. This implies that users are actually using their expensive and limited data packages to send and receive data to peers living in the same geographic area. A novel approach would be to find a mechanism that can effectively keep local traffic local by storing the most popular content in the local cloud. This way, traffic destined for the local vicinity would not have to travel the world over expensive links before being sent back to the peer living nearby. The localized cloudlet platform will leverage community-based infrastructure to host a set of cloud-based services similar to those currently available on the Internet and provide WiFi access to the community. The cloudlet platform will be made up of a selected list of open source tools namely for file sharing, private messaging, community radio/TV and social networking. Providing those services in a localized fashion will help reduce dependency on expensive cellular data network.

Once we have collected more data about most used applications and user behavior (both from survey and measurements), we can decide what content will be shared in the local cloud.

B. *Performance of WSMN device*

We have carried out some initial test measurements of the performance of the WSMN device using one fixed installation and two mobile installations and have tested their maximum capability as well as their capability with obstructions and line-of-site links.

By connecting the devices with RF cables and attenuators we could test the maximum TCP throughput using the *iperf* tool. Three measurements over 60 seconds were taken to ensure that variability in the channel is captured. To test the latency, we make use of the *ping* tool and again take three measurements over 60 seconds. Table 4 shows the average and maximum throughputs and latencies that were achieved at 20 MHz bandwidth for the fixed baseline setup. The difference in performance is negligible due to the same basic Atheros chipset being used in both devices. The TVWS Doodle lab radio down-converts the 2.4 GHz band into the 600MHZ UHF band, but the modulation level is fundamentally the same as the 5 GHz WiFi radio. Baseline experiments were conducted to determine the best performance possible on the TVWS and WiFi radios, in the absence of the effects of the wireless channel (e.g. noise, interference, fading). For the baseline experiments the network card of one interface was physically connected to the network card of a similarly kitted board through each board's antenna pigtail, RF cable, two 30 dB attenuators and appropriate connectors.

Table 4: Throughput and latency for 5GHz WiFi and TVWS link (cable)

	AVG	MAX	Latency
5GHz	22.4	24.6	0.8
TVWS	20.6	22.5	0.8

Table 5 shows the results when carrying out a test over a 500m line-of site link. The TVWS had no interference in the channel being used but there were interference sources from two sites: a TV transmitter 2 km to the South of the measurement site and a TV transmitter 8 km to the North of the measurement site. In the band of interest where the Doodle lab TVWS radio operates there are two strong digital TV signals in channel 28 (526 MHz to 534 MHz) and 38 (606 MHz 614 MHz). The signal strength of both these signals at the measurement site is -55 dBm. These strong signals cause adjacent channel interference to the TVWS radios due to non-perfect spectral masks of the Doodle lab radios. The poor input filter of the Doodle lab card causes the noise floor to rise to -89 dBm due to this distant interference source. The WiFi radio on the other hand had a noise floor of -102 dBm – hence the better performance for the WiFi radio.

Table 5: Throughput and latency for 5GHz WiFi and TVWS 500m LOS link

	AVG	MAX	Latency
5GHz	21.6	21.7	1.2
TVWS	12.4	16.8	1.7

Table 6 shows the results carrying out the test over a 3km NLOS link with a tree between the radios.

Table 6: Throughput and latency for 5GHz WiFi and TVWS 3km NLOS link

	AVG	MAX	Latency
5GHz	No link	No link	No link
TVWS	5.18	5.18	2.1

It is clear that there are scenarios where the 5 GHz performs better than the TVWS link, and scenarios where the TVWS radio provides a link where the 5 GHZ radio cannot provide any link, for example when there are trees obstructing line-of-sight. This provides good motivation for having a hybrid set of WiFi and TVWS radios.

VII. Conclusion and future work

Low cost last mile connectivity coupled with cloud technologies for affordable access to content and services is intended to provide affordable Internet access to the citizens of a township in southern Cape Town metropolitan area. The entire research is based on participatory action design. We deploy a bottom-up approach by building relationships with community members and understanding their needs first and co-developing solutions with them.

We pre-tested our method by performing data collection on a limited set of users. The next step is to increase our data set and collect data usage log from a larger number of users. Data on behavioural aspects such as ‘preferred applications’ will be collected blindly via a survey form. The idea is to cross verify behaviours of users collected from the measurement application as opposed to the responses received from the survey. The main purpose of the experiment is a descriptive study of mobile data usage characteristics. Therefore, we would make use of a cross-sectional study, through a survey and the measurement tool.

The outcome of the measurement campaign will be used as input for design of cloud services. Research outcome can be generalized to other places of Africa with similar demographics.

Our network design makes use of a White Space Mesh Node which uses a hybrid of 5GHz WiFi and TVWS to build backhaul links and 2.4 GHz WiFi for access. The network provides access in popular areas of the township such as the taxi rank and library to allow users to easily share content with each other and download commonly accessed content such as application updates.

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