Re-thinking the Connectivity for Schools Within the Public Education System in South Africa

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Abstract. Despite government and industry efforts, internet connectivity in South African public schools located in rural and township areas remains unsatisfactory. What seems to be lacking is a 'virtuous' model for an efficient and practical solution that takes into account all important aspects relating to public schools and maps them into an appropriate network infrastructure. This paper presents a model, re-conceptualising a previous model for school and community connectivity called 'Broadband Island', developed and tested within the ICT4D long-term project known as Siyakhula Living Lab. In this model, schools belonging to an educational Circuit are connected via an overlay built on top of the network provided by a local Wireless Internet Service Provider (WISP). In this model, schools benefit from having access to the Internet efficiently (via statistical multiplexing of the Internet link), through interacting with each other at high speed without crossing the public Internet, as well as sharing common educational resources hosted by the WISP. The WISP, in turn, will benefit from having a solid and well-sized customer in the form of the provincial Department of Education. The community will also benefit because the revenue generated by the local WISP will remain in the community, helping further local economic development. Finally, the reliance on local operators, as opposed to a single, nationwide implementer, mitigates the risk of a single point of failure.

Keywords: School connectivity · Community networks · ICT infrastructures for marginalized areas · Wireless Internet Service Providers (WISPs) · Broadband Island · Private cloud for education · OpenStack · microstack · Software Defined Networks (SDN)

1 Introduction

Education is an integral part of human development and is intrinsically linked to the growth and well-being of a community, including its economy [6]. The right to learn is essential, regardless of socio-economic status or background. However, the less fortunate from low-income families and those living in underdeveloped areas often cannot enjoy such a fundamental right. Delivering quality education,

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especially in low-income areas, primarily relies on the effectiveness of public schools. Many factors contribute to having a functional school, but one that is becoming increasingly important is its Information Communication Technology (ICT) infrastructure and its connection to the public Internet [21].

In this paper, we concentrate on the specifics of providing connection to the Internet to schools in marginalised areas of South Africa, i.e. townships and rural areas, and propose a model that leverages local resources to the benefit of both schools and the community hosting them. The model builds on previous work within a research initiative known as the Siyakhula Living Lab [10] and, in particular, the concept of Broadband Island developed and field tested there [22]. In essence, the Broadband Island is a wireless LAN implemented through WiMAX, an emerging technology at the time - now replaced by outdoor Wi-Fi, connecting schools in a specific geographic area. The Broadband Island was then connected to the Internet by whatever means available, which was a satellite connection in its original realisation within the Siyakhula Living Lab. The conceptualisation of the new model proposed in this paper is the result of more than one and a half years of direct daily experience with a local Wireless Internet Service Provider (WISP).

The paper is organised as follows. We first describe the typical infrastructure of a local WISP and report on the experience of its daily workings. Then we look at the state of the connectivity of public schools within the nearby local community and propose a model that the Education Department may use to provide Internet connectivity leveraging the presence of local WISP, illustrating the benefits for both schools and WISP.

2 Structure of a Typical Local WISP

Broadband connectivity for marginalised communities is mainly through mobile and fixed wireless connectivity [18]. In general, wired links are more robust and reliable, especially in the form of optical fibre, a technology spreading rapidly in South African urban areas. Wired links are costly to install, especially where the population density to be served is low, such as in rural areas or townships, and the area's geography is problematic. Because of that, small ISPs with a local footprint typically make use of wireless technologies that are not only cheaper but faster to roll out and easily deployable in an incremental fashion, shaped by actual demand. As a result, among the various possible technology choices, outdoor Wi-Fi is currently the most commonly used by local WISPs [11].

2.1 WISP Network Infrastructure

WISP networks are often referred to as fixed wireless communication because they connect fixed locations, such as a tower and a building. WISPs make use of the fixed wireless link to provide data communication used for Internet service to homes or businesses. The general structure of a Wireless ISP can be seen in Fig 1. The following description provides a brief overview of the various components and their respective functions.

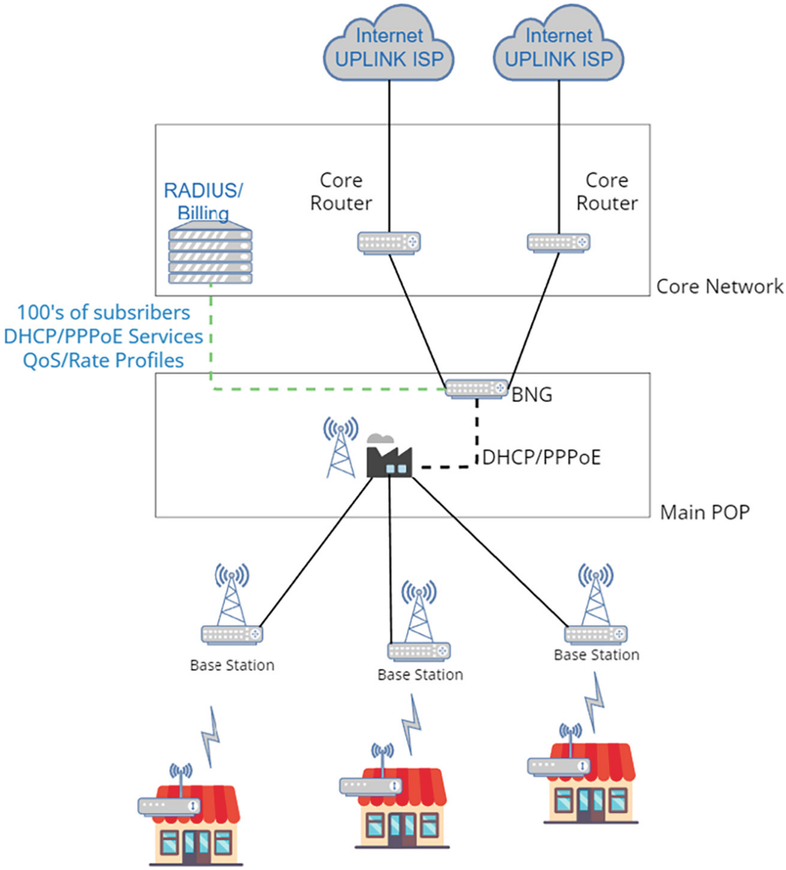

Fig. 1. ISP Network Diagram. Adapted from [1].

Core Network Infrastructure or Backbone: It comprises servers, routers, switches, and related networking equipment. This is where high-capacity data transmissions are supported, and it is where subscribers connect to the Internet.

Billing and Network Management System: This is a software component that tracks and manages the relationship between the customer and the business. It includes billing, customer services, and network management software. It maintains operations and supports customers' inquiries effectively. An example is Splynx, which features Radius to support services such as firewalls or queues to the Border Network Gateway (BNG).

Border Network Gateway (BNG): It provides functions for subscriber management and the allocating of IP addresses. As mentioned earlier, the gateway interacts with the Radius server, responsible for user authorization and termination. Radius server then grants users connectivity using Point-to-Point Protocol over Ethernet (PPPoE) [5] by assigning an IP address giving them access to the Internet. Within the PPPoE's architecture, the authentication and encryption of each user is maintained using the Point-to-Point Protocol, while the Ethernet protocol enables support for multiple users in a LAN. Typically, PPPoE consists of various elements such as servers, clients, hosts, and modems.

Customer Premises Equipment (CPE): This is the equipment located at the subscriber's premises. When the CPE is switched on, a PPPoE session is initiated, and the Radius server is contacted to authenticate and handle the assignment of an IP address. The equipment includes radios, routers, switches, and wireless devices. Customers typically connect to the Internet using the established PPPoE session through wireless devices, such as smartphones or laptops, or a wired one, such as a desktop.

Base Station: This is a hub that serves connectivity within a sub-location. It is the gateway between a cluster of customers' equipment and the backbone network. This is also referred to as the point of presence (POP) within a specific geographical location.

Backhaul Connection: It refers to the connection between base stations and the Internet backbone. It consists of high-capacity wired or wireless links, enabling the WISP to consolidate traffic and deliver high-speed service to subscribers.

2.2 Facilitating Inter-Connectivity in a WISP's Network

The architecture of an ISP network is designed to connect its subscribers with an uplink provider and manage Internet services. Packet flow is shaped and directed by routing devices to forward packets between networks. Routers share routing information using routing protocols. These protocols allow each router to maintain and advertise network links with adjacent routers. They also peer with uplink providers and are configured to advertise specific network prefixes to the public Internet and the ISP peers.

Typically, ISPs use a combination of interior gateway protocols (IGPs) and exterior gateway protocols (EGPs). IGPs exchange network reachability information within the ISP, while EGP exchange information routing information between peered ISPs.

Routing Within the WISP's Network. Routing is essential in an IP network. A router uses the routing table to make decisions. The development of a routing architecture is crucial and ensures that a startup WISP can provide the necessary performance, scalability, and resiliency for its subscribers [17]. Small WISPs commonly use Open Shortest Path First (OSPF) as their interior gateway protocol.

OSPF protocol is defined by RFC 2328 and RFC 5340 for IPv4 and IPv6, respectively [9,16]. It broadcasts network topology information between neighbouring routers and dynamically calculates the best path for data packets to take [16].

WISP networks usually implement OSPF due to its support for hierarchical organisation. It enables the creation of different areas which facilitate the control of routing within and between different network sections. This approach improves scalability and faster convergence times in case of link failures or other network problems. Additionally, OSPF features to enhance network performance, offering features such as:

- Virtual links to connect non-contiguous OSPF areas
- Route summarising to minimise routing table sizes
- Traffic engineering to control and prioritise different types of traffic

In summary, using OSPF, WISPs can maintain fast and efficient data packet delivery and ensure that customers receive high-quality, reliable Internet service.

External Routing with Other ISP. External Border Gateway Protocol, eBGP [19] is often used in the peering with other ISPs allowing for communication between different autonomous systems (AS). It enables them to exchange routing information seamlessly between their respective networks.

ISPs advertise public network prefixes to other ASes. These ASes can advertise their prefixes to the ISP's network. This ensures that routing information is exchanged efficiently, and the best path for data packets is determined based on various attributes such as network delay, link cost, and the number of hops.

eBGP maintains a globally consistent routing policy, enabling ISPs to efficiently operate their networks and provide the required quality of service to their customers. Furthermore, ISPs can use various attributes, such as route maps and access lists, to define how and when specific routes will be learned and advertised.

Figure 2 shows how a small WISP utilises OSPF and eBGP. Internally, OSPF will map out paths, speeds, and reachability for network subnets. Since links are in the same broadcast domain (Area0), OSPF updates the routing table with the routes to loopbacks (towers) and routes to customers. eBGP is used to exchange routing information between different ASes and allows the filtering of this information.

Provisioning Service to Subscribers. Managing subscribers is a vital part of local WISPs' functions, and they naturally utilise a software framework, such as Splynx [2], designed particularly for Internet service providers and network administrators. Such software is deployed on a server to facilitate user connectivity to the Internet, provide network configuration management, and manage customer relationships. The Splynx framework, for example, includes a Splynx Radius server that supports point-to-point (PPPoE) connectivity between the ISP and consumer.

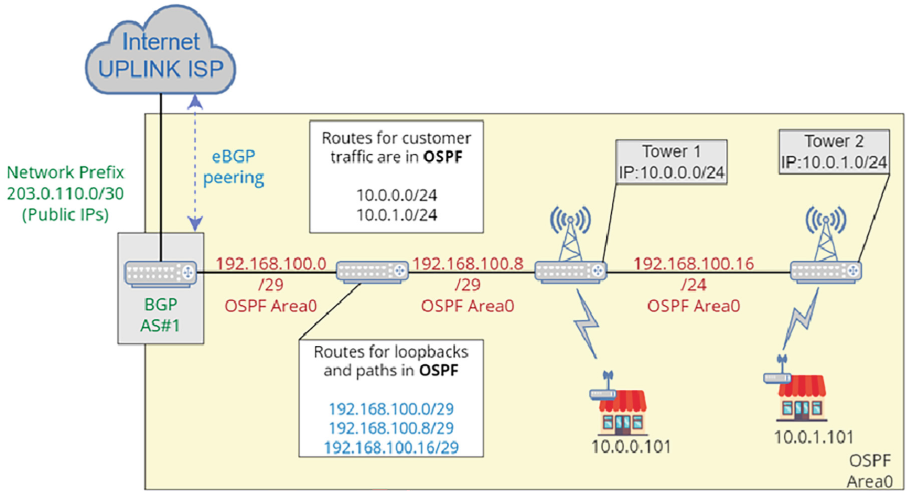

Fig. 2. Routing in an ISP. Adapted from [17]

3 Life Within a Typical South African WISP

In this section, we present one of the author's direct experiences working in a local WISP. Operating in a local WISP presents its own unique set of challenges. Day-to-day operations primarily involve setting up wireless connections, troubleshooting subscriber connectivity, managing network resources, and addressing customer queries and problems. Of course, ensuring proper maintenance is crucial and plays a vital role in delivering a positive user experience.

WISPs span a geographical area and have an influential physical component that therefore requires resources like vehicles and power tools for installation and maintenance. In general, wireless ISPs need to maintain high technical expertise, good communication, good customer service, and a willingness to learn and adapt to issues that may arise in the field.

The following subsections explore the main challenges met while working at a local South African WISP for over one and a half years. As far as we could ascertain, there is no literature on the challenges of small WISPs in South Africa. After widening the scope of the search, we found [12] which details the challenges of rural WISPs in the USA. Interestingly, the challenges reported are not very different from the ones directly experienced by us. We begin by looking at the technical issues, then move to concerns due to load-shedding in South Africa, and conclude by discussing organisational issues. We suggest mitigations for each of the listed points, drawing from our field experience.

3.1 Technical Issues

The challenges faced by each specific WISP may vary depending on factors such as location, network architecture, equipment used, and customer needs. Below are examples of Issues that are generally encountered:

Network Configuration Issues: Configuration changes may cause downtime, typically when a critical update is required. Setting up redundant links ensures service availability during these updates.

Hardware/Software Costs: The cost of obtaining critical hardware or software may be substantial, and deployment of services may be delayed due to budget constraints for acquiring new equipment. We saw that reusing spare old equipment saved us both time and money.

Equipment Failures and Connection Interruptions: Equipment failures at critical locations, like base stations, sometimes cause service disruptions. These failures may be caused by software or hardware faults. Sending messages to notify users about disconnections and scheduled maintenance lessens tension between the ISP and customers while the network is down.

Network Growth: The growth in the number of subscribers means an increase in network resource requirements. Setting a budget for development is necessary to avoid the degradation of the quality of service due to saturation on links. This may mean new equipment to upgrade capacity.

Wireless Limitations: Wireless equipment has limited range and capacity or is affected by environmental conditions. Investing in specialised equipment such as directional antennas, selecting frequencies with lower interference, and using appropriate radio frequency shielding ensures optimum operation.

Technical Personnel Shortage: The shortage of technical personnel may sometimes be unavoidable. Therefore, a proactive approach, such as automating processes, can bring more satisfactory service delivery for users.

Lack of Skills and Knowledge: This can impede the ability to swiftly address technical issues that interfere with the quality of service. Attending training and workshops is valuable and is a way to keep up with current trends and technologies.

In general, there must be sufficient technical force and resources for maintaining and running the network. As a WISP, local or not, it is expected to have high availability 'baked' into the operations as clients expect 24/7, 365 Internet connectivity.

3.2 Experience with Load-Shedding

Load shedding naturally harms the WISP space. Systems must be implemented or established to achieve a round-the-clock connection, as anticipated or desired by the customers. Experiences encountered concerning load-shedding can be summarised as follows.

Increase in Operational Costs: To ensure consistent service delivery, it is necessary to implement additional systems. This includes backup systems, generators, or solar systems. Remote monitoring systems can be expensive, but with the rise of open-source projects and the development of the Internet of Things (IOTs), building in-house solutions can save money and even allow the setting up of equipment tailored to your specific needs.

Battery-based Backup System Failure: Extended power cuts require backup systems to support 6 – 8 hr daily. This places strain on batteries due to an addition in charge cycles and prolonged discharging, meaning that batteries need to be replaced more often. Understanding battery chemistry and system requirements is essential. Specific batteries have limited discharge periods and decrease their capacity during prolonged discharging.

Equipment Failure: Power losses cause damage to electrical appliances and machinery or as a consequence of the sudden loss of power during write cycles. As a result, a device may not initialise properly when the electricity returns, thus causing service interruption.

Incidental Power Interruptions: Faults in power substations sometimes adds to the load-shedding-induced problems.

General Morale: consistent and extended power cuts can cause frustration and de-motivation among employees because of extra hours needed to keep services up. This means travelling to remote sites, re-fuelling generators, additional maintenance, and repairing equipment affected by power cuts.

In general, load shedding has brought an extra concern to deliver service efficiently to customers. To mitigate the impact of load shedding, it is critical to invest in backup power solutions to ensure uninterrupted service delivery to paying customers. Internet service providers need to plan towards a long-term solution to sustain connectivity during power cuts.

3.3 Organisational Issues

Finally, ISPs encounter various operational challenges that arise due to organisational issues. These issues include time management, inadequate resources, and miscommunication, which can potentially decrease productivity. Furthermore, limited awareness of corporate processes and performance can result in inefficiencies, missed opportunities, and a decline in morale. Addressing these challenges is crucial for enhancing the ISP's general productivity, performance, and income. These organisational issues can be reduced by:

– A well-defined strategy that will boost growth and help achieve long-term success.
– Ensuring that teams have the necessary training and resources.
– Making preparations for growth through appropriate budgeting.

4 Connectivity in Schools

We have given an insight into the general WISP operations internally and the issues faced by local WISPs. Let us examine the typical methods by which schools may connect to the Internet. The approaches to Internet connectivity in schools located in township communities may differ depending on the explicit situation. However, some common strategies include employing local community resources that offer free internet access, exploring other networking technologies, or implementing wireless internet connections designed for teaching and learning in rural schools. It is essential to note that specific models and strategies may differ based on the unique requirements and availability of resources in each community.

In theory, schools could subscribe to a service provider enabling Internet connection. But this is not always the case. In the report "Access Denied: Internet Access and the Right to Education in South Africa" we see that there are still a significant number of unconnected schools in townships and rural areas [23].

Even when schools are connected to the Internet, they operate independently of each other, even when they are located in close proximity and are part of the same education 'Circuit'. (In South Africa, a Circuit is the Department of Education's administrative zone demarcated for organising schools close to each other [7]). This is inefficient for several reasons: any communication and sharing of resources among them is routed through the Internet.

As these institutions share similar goals, it would be beneficial for them to be integrated into a single local network, allowing for more efficient communication and sharing of educational resources. The school Internet connection model we present in the next section does precisely this. Building an overlay over the network of a local WISP allows the construction of a specialised network that comprises all schools considered as an education Circuit.

5 Integrating Schools with an ISP

5.1 Broadband Island: Access Efforts for Low-Income Communities

The connectivity model mentioned above expands on the effort initiated by the Siyakhula Living Lab (SLL) to connect the unconnected [10]. As a living lab, the SLL focused on user-centered design in the structure, development, and implementation of Information and Communications Technology solutions that benefit local communities. The core artefact for the connectivity was the "Broadband Island": a high-speed wireless LAN, using WiMAX at its start in 2006, connecting groups of nearby schools [22]. The Broadband Island was connected to the Internet in a way suitable to the context. In the original implementation, in a deep rural area of South Africa in the Mbhashe municipality, the connection to the Internet was accomplished through geostationary satellites. From a technological point of view, WiMAX has been replaced by outdoor Wi-Fi, and Wi-Fi-based local WISPs have appeared and now have multiplied in South Africa. As a result, it was not difficult to see that the best way to implement the concept of Broadband Island in a commercially feasible manner is to rely on such WISPs, as will be detailed in the rest of this paper.

5.2 A Strategy for Fostering Digital Inclusion Among Marginalised Populations

The model we propose in this paper sees its viability through being beneficial to the various actors involved: the schools and, therefore, the Department of Education, on the one hand, and local WISPs, as small, medium and micro enterprises (SMMEs) and related communities, on the other. Schools need connectivity in a special form that transforms their geographical proximity into opportunities for better and more efficient collaboration. The Department of Education, naturally, needs to respond to that need as sustainably and efficiently as possible. For a WISP, presence in a community, i.e., POPs, potentially means an increase in customer base and improved business viability, especially if one of the customers is a large institution with matching finances, such as the Department of Education.

Selecting local WISPs to provide Internet connectivity has significant potential for local economic growth and is aligned with the spirit of the National Development Plan [3]. In particular, such a choice promotes SMMEs, given the fact that the majority of local WISPs are SMMEs. As mentioned in [8], the South African government acknowledges SMMEs for strategic importance in promoting inclusive economic growth, job creation, and its transformation agenda.

In the next subsections, we present our model in more detail, starting with a review of the advantages for the participants in the model and examining the model's key components, significance, and potential impact.

5.3 The Requirements for Integration in the New Model

As mentioned above, in the model, there are two primary participants: the WISP and the schools, each of them with their own needs. Schools aim to have access to information that enriches the student learning experience. Access to the Internet further enables effective communication and collaboration between teachers, students, and parents. Moreover, the Internet allows for the sharing of educational resources, including videos, presentations, and other materials, that complement traditional teaching methods. There are many open-source learning platforms and resources that are found to improve the success of learners, especially for resource-constrained communities. As mentioned in [15], the increase in the growth of users of Khan Academy shows the hunger for quality online learning resources, especially in maths. As a country with a dire need for a solution to the problem of students' maths results, schools will benefit from any form of online or offline resources like Khan Academy.

WISPs, on the other hand, aim to enhance network performance, expand customer reach, and network resiliency, among others. A better and more efficient network means better service delivery and reduced downtimes. For WISPs, the location of their base stations/POP is affected by the proximity to their existing and/or target users, the infrastructure or means for connectivity, the availability of power, and the ease of access. Security is also important.

In general, looking at the requirements for both the WISP and schools, we see that both parties provide something for the needs of the other, and they can benefit from it if they agree to work together. Consider the WISP. They require a location that can provide security, has electricity, is easily accessible, and is strategically positioned near potential users, which schools can provide. On the other hand, schools require connectivity and a local platform for students, teachers, and parents to share educational services.

5.4 Schools/ISP Integration

A collaboration between a WISP and local schools leads to establishing a new Internet infrastructure. This infrastructure enables schools to communicate with each other directly without crossing the public Internet. This can be accomplished by establishing logical connections between the schools, which become part of the WISP's network. The resulting concept is an overlay network, as shown in Fig 3. From the ISP's perspective, the schools are seen as a subnetwork within the network.

The solution we propose employs Software Defined Networking (SDN) to aid in efficiently tracking and configuring network resources, allowing the ISP to effectively manage the complexity and cater to the specific needs of both their customers and the schools. SDN enables the creation of an overlay network that sits atop the existing networking infrastructure. One of the key advantages of SDN is its ability to dynamically adapt the network state based on the specific nature of network traffic, effectively catering to the unique needs of schools and customers.

Implementing an overlay network through a Software Defined Network architecture, such as that commonly used for multi-home visual sharing [14], can further enhance the flexibility, functionality, minimise maintenance and configuration needs while future-proofing the proposed model and enhancing user experience by deploying application services that adapt to changing network traffic requirements. Figure 4 shows the interconnecting between two school networks by leveraging SDN technology. The gateway router receives traffic and enforces decisions based on the traffic engineering rules set by the controller. The traffic is then forwarded accordingly to other routers in the WISP network thereby allowing traffic coordination between schools and the rest of the WISP network.

As part of the school/WISP integration, we propose that the local WISP hosts MicroStack [4], an open-source project with an interesting history [20].

MicroStack allows the schools to deploy a private cloud environment in the local WISP headquarters. It doesn't require costly infrastructure, rendering it a cost-effective solution for schools with tight budgets. Teachers, students and administrators would be able to create virtual learning environments, share resources, and host collaborative spaces where students can work together on projects and assignments. Additionally, using MicroStack, schools can create personal learning facilities, for teachers to provide students with more individualised attention to cater to specific learning needs.

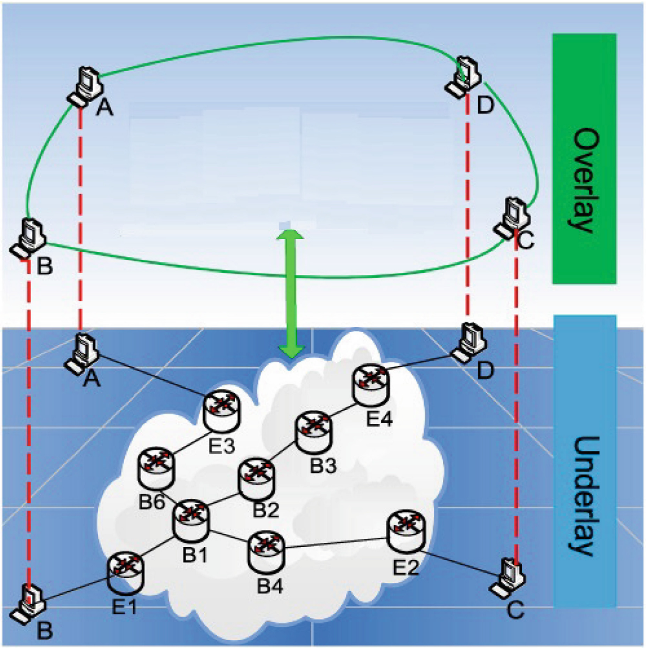

Fig. 3. Overlay Network [13].

5.5 Benefits of School/WISP Integration

The benefits of integrating schools with a local WISP network are many-fold. The main advantage for schools and indirectly for the WISP is the faster and generally more reliable data delivery since all traffic is destined for a local point, such as another school in the WISP's school network overlay. This results in much lower latency for data communication and a better user experience, especially for real-time services such as distributed synchronous video lectures. The architecture, keeping local traffic local and multiplexing the traffic exiting the school network overlay, also reduces the total amount of the traffic on the more costly WISP

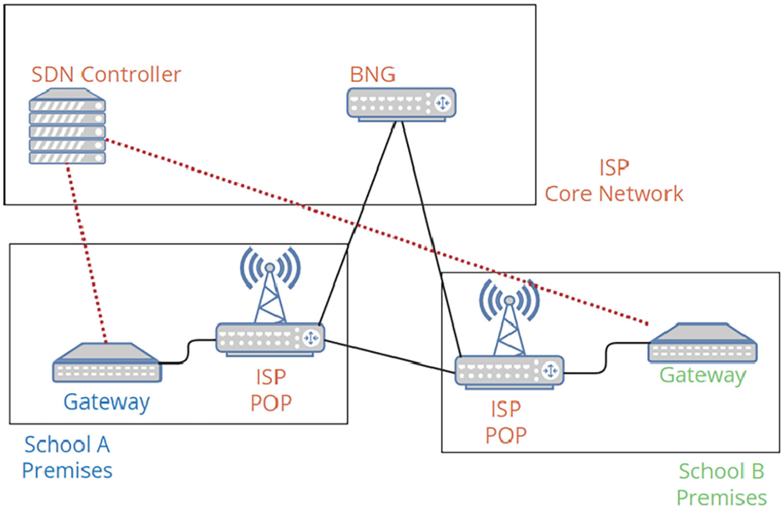

Fig. 4. An SDN-enabled school-networking environment with an SDN Controller connecting to each school gateway. The controller and Gateways coordinate inter-school and intra-school networking, respectively.

uplink to the Internet, allowing the connection of more schools with only a marginal need to increase capacity on that link.

For the local WISP, the partnership with the Department of Education for the management of school traffic will inject capacity, resources, and revenue into its business, directly benefiting the economy of the community of which the schools are part, given the local nature of the WISP. If used effectively, the additional resources gained by connecting schools can enhance the quality of service delivered by the WISP, increasing its stability and capacity to address the earlier-listed challenges. This, in turn, can attract more customers, potentially initiating a 'virtuous circle' that fosters WISP growth and extends connectivity to more homes.

The community itself, of course, will benefit from the presence of a more robust WISP. In particular, such a WISP could potentially increase its points of presence to remote locations to connect remote schools on behalf of the Department of Education, thus making it possible for private homes in that area to connect to the Internet. This would help with the general effort of spreading broadband connectivity in marginalised communities of South Africa.

6 Conclusion

In this paper, we presented a model for Internet connectivity for public schools in South Africa. The model is an evolution of a previous model conceptualised with the Siyakhula Living Lab and proposes the construction of an overlay network for the schools administered by a specific education Circuit in the network of a local WISP. The model might be able to change the unsatisfactory situation of Internet connectivity in public schools, even after more than two decades of attempts by the government to solve the problem.

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