

Using TV White Spaces and e-Learning in South African Rural Schools

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Abstract: This paper uses the example of the television white space (TVWS) project in Limpopo Province of South Africa to consider benefits of TVWS technology to enable e-Learning environment and introduce pupils and teachers previously unfamiliar with Internet to information and communication technologies (ICT) including Internet. The Limpopo TVWS project uses TVWS to provide broadband Internet to five schools which are up to 10 km away around the University of Limpopo (UL) in the rural Mankweng Township. Each one of the participating five schools was donated 31 tablets, an overhead projector and smart phone to enable e-learning delivery. The paper presents preliminary results on a socio-economic study conducted at the five participating schools, and also discusses various benefits of availability of connectivity and of e-Learning.

Keywords: broadband, e-Learning, Limpopo, rural broadband, television white space, trial, TV white space.

1. Introduction

According to the e-Learning Africa Report of 2014 [1], e-learning is becoming a necessity, and not a luxury, as demand for distance learning and higher education in Africa increases. Such demand is also supported by the availability of Information and Communication Technology (ICT) infrastructure to most people living in urban areas [2]. However, there is still a number of people living in rural areas where there is inadequate or non-existence of ICT infrastructure to support delivery of e-learning. Such example is the rural communities around the Mankweng Township in Limpopo Province, South Africa where the majority of local schools have no access to ICT infrastructure [3].

The purpose of this paper is to present preliminary results on the work that is being done to provide Internet connectivity and educational services and e-learning to the five rural schools which *never* had access to internet. The broadband Internet access is provided using the television white space (TVWS) technologies. We start the paper by introducing the field, and then continuing/proceeding onto the Limpopo TVWS trial network. We then present the preliminary results from the impact studies conducted on the five participating schools. The paper also discusses the business and other benefits of using TVWS technology to address ICT connectivity for enabling e-learning in developing countries.

1.1 E-Learning for 21st Century

The advent of advanced Information and Communication Technology (ICT) has not only transformed the global economy, but it is also changing the way education is delivered to the learners. The use of ICT for delivering education and training is commonly known as e-learning. Examples of e-learning processes are in sharing well-trained teachers with

multiple schools by teaching over the Internet, providing and evaluating exercises remotely, replacing textbooks with electronic readers etc. E-learning promises to revolutionize the education system in the 21st century through offering new ways of learning and teaching. Through e-learning, learners can access knowledge or information from anywhere in the world, at any time convenient to learners, as long as they are connected to the Internet [4]. With affordability and availability of portable devices, such as tablets, learning is no longer limited to the classrooms.

E-learning became more dominant in post-secondary education and training such as in universities and colleges. The Massachusetts Institute of Technology (MIT) was among the first universities to promote e-learning through their OpenCourseWare initiative [5]. Through this initiative, MIT has published all their educational materials online and it is available openly to anyone. Today, e-learning is being used by many universities around for contact and distance learning.

E-learning is also starting to find its place in the secondary and primary schools in both developed and developing countries. In South Africa, for example, the Department of Basic Education (DBE) is in the process of adopting e-learning in secondary schools by replacing physical textbooks with e-textbooks for a full e-learning environment [6]. Some other e-learning initiatives in rural schools include the Cofimvaba Schools District technology project where the DBE together with the Department of Science and Technology (DST) are piloting the use of technology innovations to facilitate e-learning in rural schools [7]. The Cofimvaba project is focused on supplying teachers with tablet and providing Wi-Fi connectivity to 26 schools in the Nciba Circuit, Eastern Cape Province, South Africa. e-Schools' Network in South Africa is also working on providing connectivity to schools by negotiating low prices with Internet Services Providers [8].

Despite many advantages brought by e-Learning over traditional face-to-face learning, there are still challenges that should be addressed in order to realize full benefits of e-learning, especially in developing regions. One of these challenges is the lack of ICT infrastructure in rural communities and schools. ICT infrastructure refers to both the devices (such as computers or tablets) and the telecommunications infrastructure which brings Internet connectivity. A comparative study between under-funded (mostly rural) and well-funded (mostly urban) schools in South Africa has shown that there are a number of schools in rural areas without Internet connectivity [9]. At the same time, it is well known that a 10% increase in broadband penetration yields an additional 1.38% in the national GDP growth [10], hence one needs to ensure availability of connectivity to reap the full benefits and long term growth arising from ICT. In order to address the connectivity gap, there is a need to find reliable and cost-effective solutions to provide broadband connectivity to rural schools. The next subsection introduces the TVWS as a promising technology for rural broadband connectivity to support e-Learning.

1.2 Television White Spaces for Rural Broadband

Connectivity is key to bridging the digital divide. The South African Government provides strong support to broadband innovations. In a recent example, the Department of Communications issued a national broadband policy named SA Connect in December 2014 [11]. The policy recognises spectrum as a scarce resource, and sets a number of priorities. These include the identification of unused spectrum and its reassignment; approval of spectrum sharing between spectrum licensees and across services; and enabling of dynamic spectrum assignments, while safeguarding the spectrum commons and spectrum required for public access technologies and services [12].

One particular area holds a strong promise to provide inexpensive, reliable and rural-suitable means for broadband connectivity for rural areas. TVWS refers to portions of assigned radio frequency spectrum on the ultra-high frequency (UHF) television band (470

– 694 MHz) which are not utilized at a given time in a given geographical location [13]. The UHF spectrum is assigned for the primary use by the television broadcasting (with a few exceptions related to the Radio astronomy and studio links). In the past few years, the Council for Scientific and Industrial Research (CSIR) of South Africa and others conducted several spectrum availability measurement campaigns in selected urban and rural locations in Southern Africa and abroad, and found that there is a substantial amount of spectrum, especially in TV frequency bands available and ready to be exploited for broadband Internet connectivity [14], [15], [16], [17], [18]. These available portions of TV bands are the TVWS. Based on those studies, there is growing recognition across the globe that a dynamic way to spectrum sharing (contrasted to the traditional static spectrum assignments), especially on TVWS, enabled by geo-location databases, has significant potential to increase the availability and ubiquity of broadband access [19], [20].

The CSIR has been engaged in dynamic spectrum sharing research since 2009. The breadth of research, development and innovation (RDI) activities at CSIR include spectrum decision frameworks [21], channel allocation algorithms [22] and the development of a geo-location spectrum database [23], as well as TVWS test-bed deployment projects [15].

In particular, the TVWS trial held in Tygerberg, Cape Town, South Africa provided broadband Internet connectivity to ten schools with over 9,500 pupils and teachers [24]. Some of the less privileged schools had TVWS Internet as the only means of Internet access, as the copper cabling for their ADSL lines was stolen. In addition, as per [12], the positive results of the trial have been mentioned by the Federal Communications Commission (FCC) in the document 14-144 and were part of the reason the US regulator decided to relax the guard band requirements for TVWS. In South Africa itself, the CSIR and Google are in the process of drafting a white space regulatory framework submission to assist the South African regulator with the processes.

Moreover, some of the world's most developed countries, such as USA, UK, Singapore, as well as many other African countries, such as Tanzania, Malawi, Kenya, Namibia and Ghana have welcomed or are welcoming TVWS. For example, USA has TVWS legislation already for several years and permits running commercial services.

1.3 Paper Outline

The remainder of this paper is arranged as follows. Section 2 provides the objectives of the paper. In Section 3, the Limpopo TVWS trial network topology is discussed. Section 4 provides preliminary findings on socio-economic impact of the TVWS network and outcomes of e-Learning provision in participating schools. The benefits of connectivity and, specifically TVWS as an alternative and cost-effective option to providing Internet connectivity to rural school for enabling e-learning delivery are discussed in Section 5. Section 6 concludes the paper.

2. Objectives

The objectives of this paper are as follows.

1. To emphasize the importance of e-learning in schools for inclusive education, especially in marginalised areas such as rural schools.
2. To propose an innovative TV White Space (TVWS) based solution and outline the technical architecture of the Limpopo TVWS trial network serving the needs of e-learning.
3. To present the preliminary results of the Limpopo TVWS trial networks being a part of e-learning. This trial network connects five schools, which have never experienced Internet connectivity, in the rural community surrounding the University of Limpopo in Mankweng area, Limpopo Province, South Africa.

3. The Limpopo TVWS Trial Network and end/user devices

The initial use case for Limpopo TVWS trial was to connect five local rural schools to the Internet. The five schools were then selected through support from the University of Limpopo's (UL) School of Education and Department of Computer Science. The schools were selected to provide a mixture of schools between quintile 1 (poorest) and quintile 4 (least poor). The current network connects the UL TVWS centre (which is also a test-house for the technology) and the five high schools located within 10 km radius from UL campus in Mankweng Township. The trial network is designed in a star topology with a base station (BS) site located on the rooftop of the UL library, as shown in Figure 1. Due to absence of the line of sight between the UL and Ngwanalaka HS, Mapeloana HS is used as a repeater linking the BS at the UL with Ngwanalaka HS. While Mapeloana is not among the five participating schools, it benefits by receiving free Internet access accessible at the school through WiFi on individual laptops.

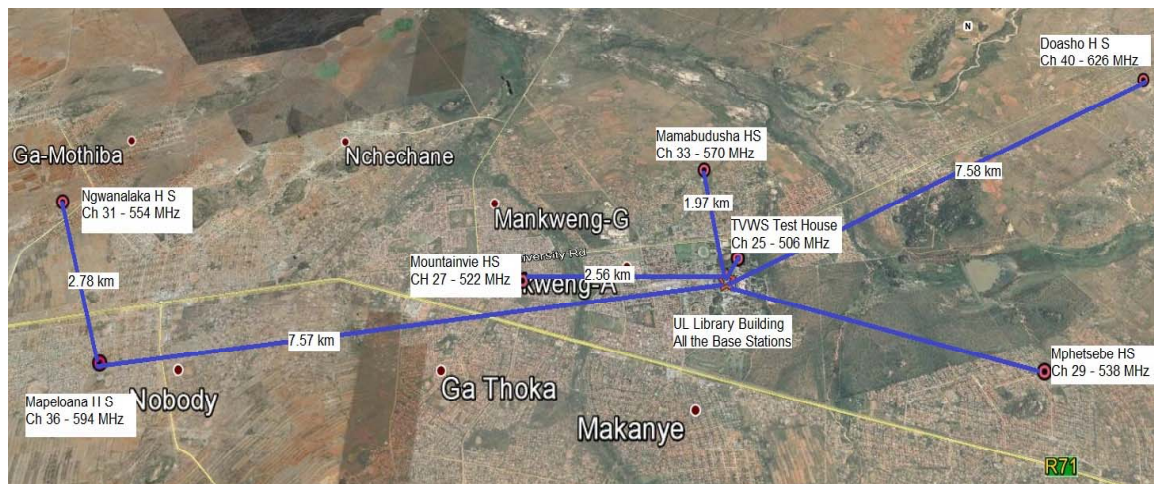


Figure 1: Limpopo TVWS Trial Network Layout showing distances from the BS at UL library to each CPE site and the TV channels used per CPE.

In its current form, the Limpopo TVWS trial network operates in a point-to-point (PtP) configuration whereby each one of the six client premises equipment (CPE) is directly linked with its own BS. The point-to-point (PtP) trial network layout was mainly considered to maximize the throughput of the TVWS connections for each of the schools but is suboptimal economically and in terms of usage of spectrum. There are plans to improve the network to support point-to-multipoint configuration in the near future.

Figure 2 below outlines the network design for interconnection between wireless devices (such as tablets and laptops) and TVWS CPE or point of presence within a typical school. Every school, including the UL TVWS House, has equipment with a TVWS CPE which is connected to the access point (AP). Thus, the TVWS link can be viewed as backhaul provision to each school. In order to minimize radio frequency (RF) cable losses, both the TVWS antenna and white space device (WSD) are mounted on the pole.

A combination of TVWS antenna and WSD makes up the CPE. Each CPE is capable of transmitting up to 26 dBm of Effective Isotropic Radiated Power (EIRP), which is 20 dBm by WSD plus 6 dBi due to the antenna gain. The CPE is then connected to the router board (RB951) Wi-Fi access point which provides wireless local area network (WLAN) to be accessed by tablets, laptops and smart phones at each school.

Each school is designed to provide Internet landing speed (i.e. backhaul link per radio) of 10 Mbps with a target TCP throughput per schools of between 5 and 10 Mbps. There are ongoing studies aimed at studying the actual Internet access speed or throughput at each school, and this will be reported in our future work.

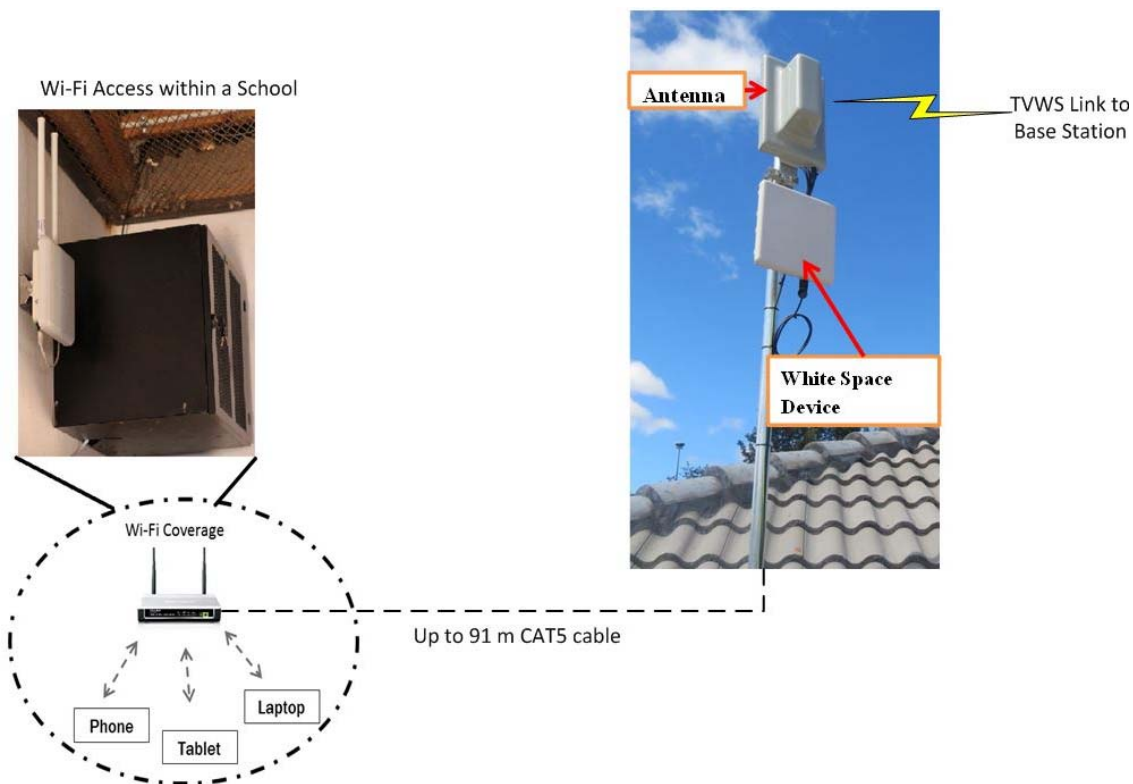


Figure 2: Typical network design showing the interconnection between TVWS backhaul and wireless devices for each school

The immediate societal impact of the Limpopo TVWS trial is the connectivity of 5 rural secondary schools, connecting a total of 5,335 students and 164 teachers, to the Internet for the first time. Each school was allocated 31 tablets and one laptop for educational purposes. Table 1 summarises the statistics of TVWS trials per schools.

Table 1: Statistics on TVWS trial impact to rural schools

	Total Students in School	Students using Internet	Teachers using Internet	Tablets Provided for TVWS	Laptop Provided for TVWS	Smart Phones
Doasho High School	790	370	32	31	1	1
Mamabudusha High School	750	81	21	31	1	1
Mountainview High School	1830	450	60	31	1	1
Mphetsebe High School	1215	55	30	31	1	1
Ngwanalaka High School	750	81	21	31	1	1
TOTAL	5335	1037	164	155	5	5

4. Limpopo TVWS Socio-economic impact analysis: learners and teachers survey results on digital and literacy views

The trial included provision of ICT infrastructure and upskilling teachers and selected learners, who did not previously have much access to computers, Internet and other aspects of ICT. Microsoft, one of the key partners of the Limpopo TVWS project, has provided much of the required equipment and organized training in collaboration with the UL.

This section shows the importance of ICT in teaching and learning, with ICT supported by both teachers and learners. The respondents of this study declared that ICT provides better opportunities related to furthering of studies and career progression. Although most of the respondents did not have most of the necessary skills, some managed to learn on their

own and used self-acquired knowledge. The evidence provided is both quantitative and qualitative in terms of form, analysis and interpretation.

Throughout the study, around 600 respondents completed the questionnaire focused on their ICT skills and relevant topics. The TVWS Pilot Project schools are characterised by learners who are mostly between the ages of 16 and 19 across grades 8 and 11. They typically walk to and from their schools on a daily basis. These respondents most frequently come from households of between 4 and 7 family members, and whose home language is Sepedi. Most of the respondents' interests after completing grade 12 are to further their studies in a higher learning institution instead of looking for the job. Furthermore, the responses from the sampled learners indicate that the majority of them are interested in maths, science and technology related subjects. However, they indicated one of their major challenges as being the lack of necessary equipment to conduct practicals. Furthermore, they often had to rely only on explanations from textbooks for acquiring new knowledge. The study is presented with two main subsections presenting views of learners on digital literacy and teachers' perspectives on ICT and related literacy.

4.1 Views of learners on digital literacy

In order to understand the views of respondents towards the importance of digital literacy, a scale from 1 to 10 was used, where 1 and 10 represent 'completely disagree on importance' and 'completely agree on importance', respectively. Although the majority of respondents indicated that they do not have access to ICT infrastructure, they still strongly believe that ICT related skills are necessary to survive in today's world as shown in Figure 3. The respondents further confirmed that they need the ICT skill to progress in their careers. Even though there are tablets in their schools, the majority of the respondents indicated that they have never used them nor seen them before. They explained that the tablets were used by a few selected learners (who are mostly in higher grades) and the teachers. This is mainly due to the limited number of tablets (i.e. 33 per school) used by a selected few learners for their lessons versus the total number of learners who participated in the survey.

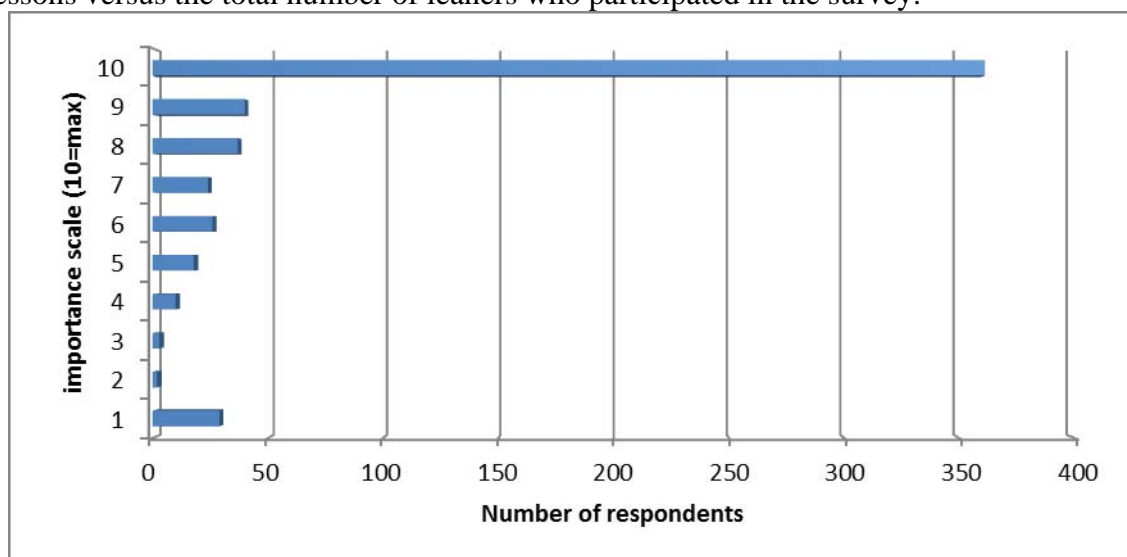


Figure 3: Respondents' Views on Digital Literacy

Another reason given for not using the tablets was the fact there were very few tablets to be used by the entire school. However, some learners used their smart phones to access the wireless Internet (provided by the TVWS project) in order to access social media for communication purposes, e.g. with Whatsapp, Facebook and Tweeter. While the use of social media may have a negative impact to learning, it can be viewed as a measure of Internet usage and part of enabling people to learn the Internet and its services. Technical

measures can be easily put in place to restrict social media usage during the learning periods.

4.2 Teachers' perspectives on ICT and related literacy

This section discusses four perspectives on ICT and related literacy, namely: digital literacy attitude, confidence with basic computer operations, applications and usage of web. Digital literacy attitude study considers how the respondents view ICT as a tool for effective teaching and learning and uncovers the respondents' level of ICT skills. Through knowing the respondents' basic computer applications, their digital literacy is determined. In terms of the confidence in working with the applications, the respondents' ability to use Microsoft Office applications is established. To uncover the respondents' confidence in using the web, they were asked about their ability to perform web related activities such as sending and receiving e-mails and downloading files from the internet etc. The respondents' overall responses help to evaluate the level of e-learning skills.

4.2.1 Respondents' basic computer operation opinions

With regard to literacy views, the opinions of respondents on basic computer operations, Microsoft Office applications and web confidence will be discussed. The majority of the respondents (19 teachers) confirmed that they are very confident that they can turn a computer on, log into and switch it off, as illustrated in Figure 4. None of the respondents is unable to turn a computer on, log into user space or switch a computer off.

However, the ratio of respondents decreases when it comes to being very confident in copying, moving, deleting, finding and downloading files, as well as downloading and installing new programs and applications on a computer. This is shown in Figure 4. Two respondents confirmed that they are not confident that they can copy, move, delete, find and download files compared to the 7 respondents who are not confident to using a computer. Some respondents declared that they do need assistance to be able to successfully copy, move, delete, find and download files; and, download and install new programs and applications on a computer.

Even though most respondents asserted that ICT skills are important for teaching and learning, the results of the survey shown that they still do not have the required skills.

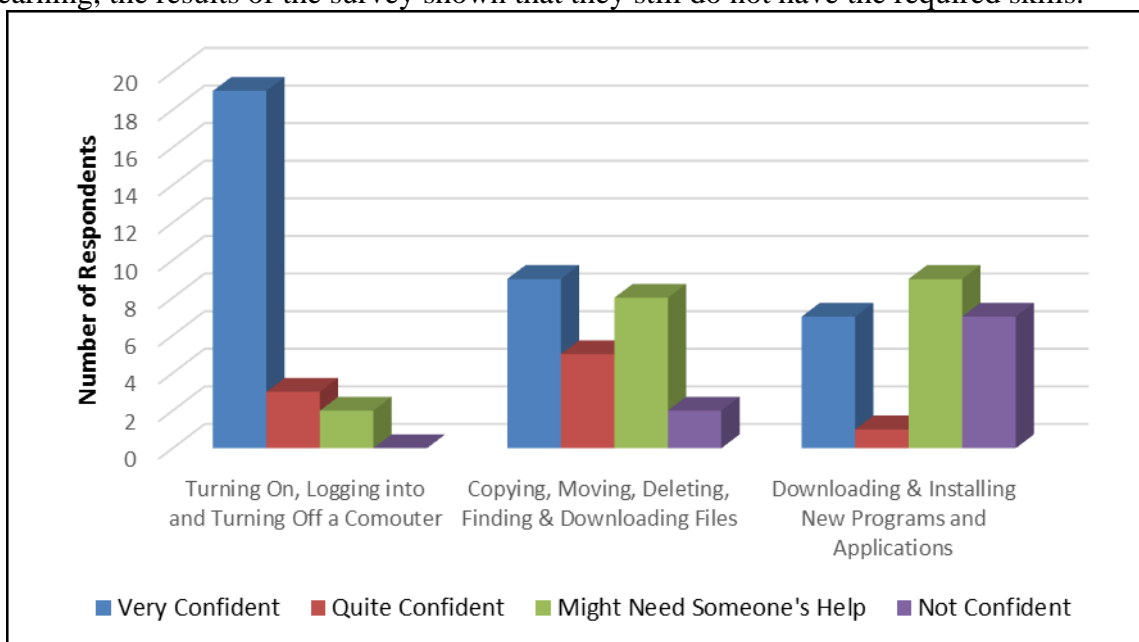


Figure 4: Opinions of Respondents on Basic Computer Operations

4.2.2 Opinions of respondents on using Microsoft Office

The usage of Microsoft Office applications is also an important element in ICT which could be used to improve teaching, learning and administration in schools, and is thus also considered as a figure of merit. The majority of respondents (15 teachers) are very confident in the use of Microsoft Word as compared to 11 and 6 respondents for Excel and PowerPoint, respectively, as shown in Figure 5.

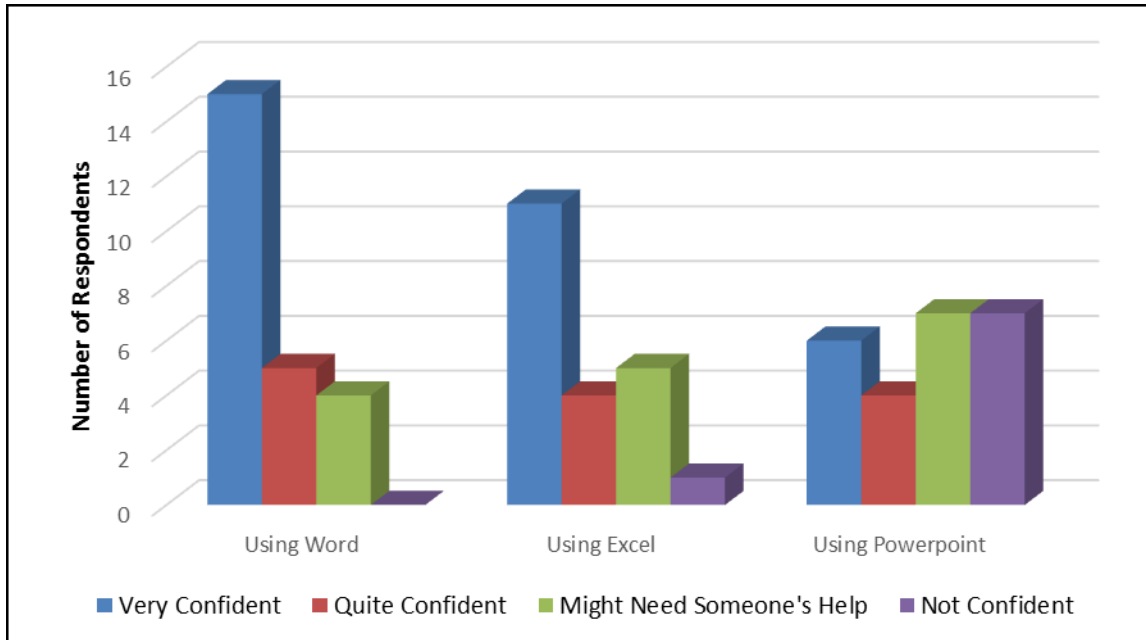


Figure 5: Views of Respondents on Using Microsoft Office

Most of these respondents explained that using Microsoft (MS) Word is easy as compared to Excel and PowerPoint applications. Typing MS Word documents is simpler than using formulas on Excel and preparing slides on PowerPoint. As shown in Figure 5, 5 and 7 respondents confirmed that they definitely need someone's assistance when using Excel and PowerPoint applications, respectively. The reason may however be simple: some of these respondents indicated that they hardly have a need to use these applications. As a result they do not see the importance of excelling in using them.

4.2.3 Respondents' views on using the web and online applications

One of the major functions of the computer is to be able to access the web for multiple purposes which include receiving and sending e-mails and downloading materials from the internet. As shown in Figure 6, 11 and 8 respondents declared that they are very confident in searching materials and downloading files from the Internet, respectively. Some of these respondents rely on a number of sources which include the Internet for lesson preparations. Only 3 and 6 respondents do not know how to search for materials and download files on the Internet, respectively. Most of these respondents (i.e. teachers) do not possess the required ICT skills and do not use it in their teaching. Even though some respondents indicated that they have not been trained to use IT, most of them are still able to receive and send e-mails. A total number of 12 and 6 respondents confirmed that they are very and quite confident in using the web to send and receive e-mails, respectively, as shown in Figure 6.

Most respondents indicated that being the beneficiaries of the TV White Spaces Project also assisted them in having access to their personal accounts. However, there are still those who have personal e-mail accounts but still need assistance to use them, as a result of lack of training in IT. In terms of creating an online account and logging into an online service,

as many as 13 respondents declared that they are not confident and could not do that on their own. Some of these respondents explained that creating and logging into an online service requires advanced ICT skills which they do not have.

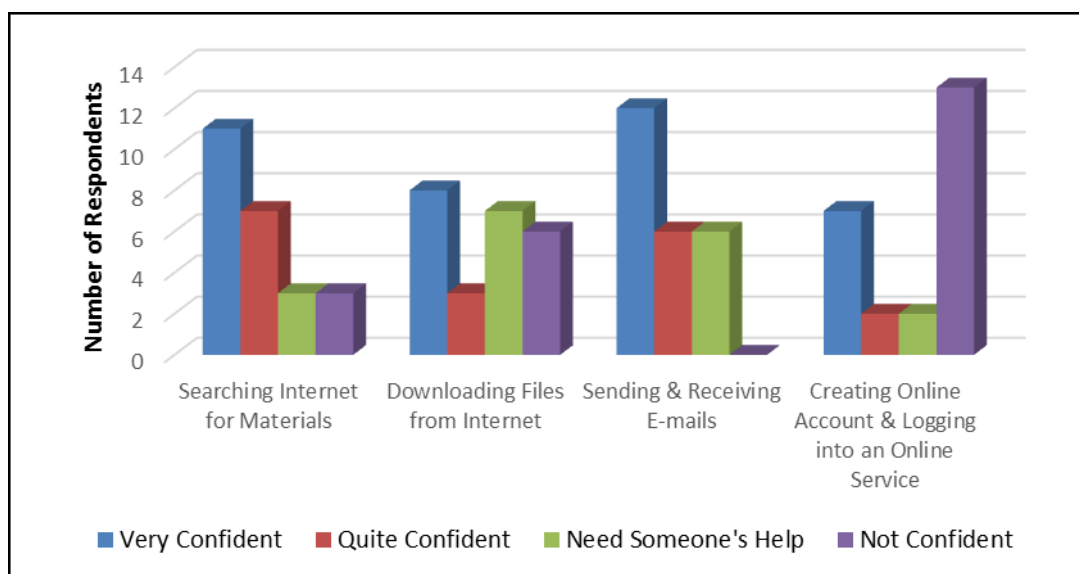


Figure 6: Views of Respondents on Using the Web

4.2.4 Summary

Generally, most respondents have basic ICT skills which they use for their teaching and personal communications. Some of those who do not have the skills are learning on their own how to use computers and the Internet with the help of the tablets and skilled colleagues. The respondents who are not able to use computers and are not even willing to learn indicated that they do not see a need to acquire the skills as they do not use them in their teaching.

5. Benefits

There are a number of different dimensions and perspectives to describe the benefits arising from providing Internet connectivity to schools in rural areas. In terms of the e-Learning itself, the general benefits of good connectivity are tremendous:

- Availability of up-to-date quality teaching and reference material, including rich multimedia.
- Ability to share resources, such as lecture and class notes, communicate with other pupils having similar problems, look for solutions beyond the classroom.
- Offering teachers and administrators easier way to search for opportunities, e.g. scholarships, for their pupils, and to report on the progress to both government and to participating parents.
- Offering governments a much quicker and more convenient ways to collect reports from the schools, also permitting to take action when it counts, without a delay, e.g. if some materials were not delivered to a school.
- Increasing the ability of pupils to successfully find jobs. On one hand, this starts with ways to look for jobs, which are most widely posted on dedicated web sites on Internet and normally require good web browsing skills.

In addition to the immediate benefits to e-Learning, there are also longer term advantages of connectivity to both the individual learners, school, community and country, such as:

- Connections may be shared with other local services, such as clinics, enabling e-Health applications.
- Furthermore, even relatively narrowband connections may also be conditionally shared with local population. This should be feasible since the school's priority traffic is normally linked to school operating hours, which usually do not overlap with evening time when many people return from work/field and would want to use Internet to browse Internet, send e-mails, do downloads etc. This would equip an even greater portion of the local population with access to ICT services.
- From a business perspective, access to Internet may assist to local businesses, regardless of how small: to promote and sell their products and services, and to purchase goods and services at optimum prices. For example, Internet access can be used to assist interested farmers to learn and become more competitive.

The above-mentioned benefits concern any type of connectivity available. TVWS, however, offer specific economic advantages. This is due to the longer distances they can cover using the same radiated energy and due to large amount of bandwidth they can offer in rural environments. For example, transmitting at the UHF frequency of 600 MHz may afford up to 4 times longer distances and/or 16 times larger area than transmitting at a common Wi-Fi frequency of 2.4 GHz. This may translate into up to 4 times less repeaters to link up an isolated remote village, or up to 16 times less transmitters to cover a large area with sparse population. Such advantages, combined with the speeds of 5 to 16 Mbps available with the current TVWS technologies can make a significant difference in providing broadband Internet enabling true e-Learning environment. The upcoming technologies promise to take advantage of hundreds of MHz of white space spectrum available, thus opening possibility of extremely fast, truly broadband connectivity and multimedia-rich educational and other services.

Specific to this trial of combining technology and education, another important note is the provision of broadband Internet access, which in this case was enabled by fast TVWS technology, permitted teachers and learners to start acquiring the critical ICT skills, making the more competitive with respect to typically more advantaged urban learners and offering them new opportunities.

6. Conclusions

The paper describes a practical application of the television white space (TVWS) technology to enable an e-Learning environment at five rural schools without prior access to or experience with Internet, around University of Limpopo in South Africa. The Limpopo TVWS project covered nearly a complete value chain, from providing telecommunications infrastructure/Internet back-bone based on TVWS, to providing equipment and skilling up teachers and selected pupils in the schools to start them up with ICT. The learners in the schools have been interviewed to establish their level of skills in the usage of the computer equipment, common software tools/programs and web and online services. The results of the interviews have been discussed and indicate that ICT upskilling is possible and can be enabled and supported by TVWS based technologies. Future work includes the performance analysis of the TVWS links as well as understanding the network throughput when the number of wireless devices increases.

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