PowerLine Communications an Integrative Solution to Digital Divide and Broadband Delivery for the Non-Broadband Communities of South Africa

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Abstract—Ensuring Broadband delivery and addressing Digital Divide needs integration of solutions that positively influence and affect the "Broadband for All" theme in South Africa. The authors argue that though relatively new, Broadband PowerLine Communications (PLC) is capable of solving the Digital Divide problem, characterizing the non-broadband communities of South Africa. Besides defining what is, Digital Divide and citing the advantages of the broadband PLC technology, the study present a comparative analysis of the PLC Network and the Ethernet Network under FTP load experiments in an Open Source Software Environment. The research investigates the competitiveness and comparability of PLC Network as technology that can bring substantial effect to the South African non-broadband communities if implemented at an extensive scale.

Index Terms—Broadband PLC, "Digital Wall", Broadband Delivery.

I. INTRODUCTION

A. Digital Wall not a Digital Divide in South Africa

Since the advent of broadband, much of the Southern African Region ICT projects' benefits have not been seen forthcoming as initially projected [1]. The overall interpretation that avails is that, if it was the Digital Divide problem then a lot of bridges might have been built and by now the non-broadband communities would have shown noticeable growth leading into the global information society. Although a lot of work has been directed to building bridges still ICT development in Southern Africa is most aptly described as rather stagnated [1]. Why? This brings into light the reality that, bridging the digital divide is a non-trivial task that demands, addressing, the digital wall that hinders the infiltration of ICTs into non-broadband regions. In this, paper we argue that with the de-structuring of the previous slanted system only can Southern Africa have growth to accomplish the "Broadband for All" theme. What is retarding Broadband delivery in South Africa is not in the technology but it is in the literature and definitions of what is Digital Divide in Southern Africa. The Digital Divide problem is being solved with the wrong definition and instead of finding ways to deal with the "Digital Wall" ("Digital Border" or "Digital Boundary") all levels are busy building bridges over the "Digital Wall". Digital Divide [2] as defined by researchers in the developed world is the same definition being used by the contemporary researchers of the developing world. The developed world definition is at large devoid of the past and present experiences of the developing world. The developed world is very much different from the developing world in particular Southern Africa. The differences in their history and development make it less sensible for Southern Africa to adopt the same term Digital Divide. All because the focus it carries cause Southern Africa to solve the Digital Divide problem with the mindset leading to a slow growth in ICT deployment in the Southern Africa.

The Digital Divide definition is lacking. In the context of Southern Africa, it is limited due to the fact that the Digital Divide problem was intentional and came into being solely because of a previous system that had slanted policies, which encouraged separate growth [3]. The system of separate growth led to the piling up of restrictive policies, that produced the "Digital Wall". It is the strong contention of this paper that in Southern Africa, the term Digital Divide is inapplicable and does not fully accommodate all the reasons (or causality) why the problem existed in the first place. We are addressing a problem that has been wrongly defined. Applied to South Africa Digital Divide definition is a misfit. It is against such a backdrop that this research exerts the fact that it is rather best described as a "Digital Wall" within the context of Southern Africa.

So how can Southern Africa in particular South Africa take the Digital Divide definition and coin a term that best, describes and inculcates more meaningfulness to the present and future problem of information haves and information have-nots. Such a failure in a way has stifled Broadband Delivery in Southern Africa. So there is great need to find solutions around the "Digital Wall" ("Digital Border" or "Digital Boundary") and by that Southern Africa will achieve "Broadband Delivery for All" else it will remain unresolved. The gap between the information haves and have nots in Southern Africa is not empty, there are issues that are piling up blocking the ICT outreach mechanisms and these have become to be known in this paper as the "Digital Wall" problem. The perspective of this paper is that, broadband communities in Europe are separated by a gap termed the Digital Divide but in Southern Africa, it is not a gap and it has never been a gap but a problem better explained as a "Digital Wall". In the following sections, Broadband PLC is acknowledged as a Broadband Delivery solution with capabilities favorable for broadband communication in the last mile.

B. Previous Broadband PLC Research in South Africa

Electrical power supply networks have been used for telecommunications since the beginning of the twentieth century [4]. During the last years, the concept of providing broadband Internet access through a low voltage distribution network dawned on the research community [2]. The penetration of PLC in South Africa and Africa at large has not been without difficulties. In the mid 1980s, several entities investigated the electricity grid as a medium for high-speed data transmission. In South Africa PLC was initially investigated at the University of Johannesburg in the late 1990s, and was deemed to be a failure**.** The results of the PLC research were negative and led to the withdrawal of University of Johannesburg from PLC research [5].

In 2003, PLC research was undertaken using the Ascom technology at Rhodes University. It was discovered that while the technology had potential, it was not mature enough for wide deployment [6], also it was cost prohibitive for usage in rural areas, and the bandwidth was not high enough to compete with other alternative broadband solutions [6]. This is understandable given that the Ascom technology has a bandwidth of 45Mbps. In this century, regulations are making PLC deployment feasible and PLC technical problems are being solved through production of chipsets with high bandwidth capabilities.

Previous effort in the area of PLC by the Telkom Center of Excellence at Fort Hare University, has already analyzed some aspects of PLC since 2003 as a last mile access technology. [5] highlights the first PLC research done at Fort Hare University using the Ascom technology. The research project built the low voltage PLC network, evaluated its performance and examined its applicability within the Small Micro-Medium Entrepreneurs (SMME) usage context. The discussion of the results of tests carried out through Iperf memory transfers showed that PLC was a technology capable for broadband delivery [5].

In 2004, Fort Hare University investigated Internet access over PLC networks [7]. The PowerLine network was deployed using the InovaTech HS PLC technology, which has a raw data rate of 45 Mbps for each link**.** However, the PLC network had erratic connectivity status [7]. The implementation of a PLC based telephony system in a multi-building setting was undertaken in 2005. In this research, the PLC telephony system was implemented at Fort Hare University using the second-generation Mitsubishi PLC technology that offers 200Mbps. The voice signals were transmitted and telephone links were established through out the PLC telephony network [8].

Companies in South Africa have carried out PLC field trials in public low voltage distribution networks. The large-scale PLC field trial in South Africa was first carried out by Tshwane Municipality. Grintek Telecom, Goal Technology Solutions, Tshwane University and City of Tshwane Metropolitan Municipality performed the PLC deployment in Pretoria [9], [10]. The Tshwane University in collaboration with the City of Tshwane Metropolitan Municipality initiated an interactive tele-teaching pilot project to a nearby school as a community project [9]. The PLC installation at Rooiwal village in Tshwane demonstrated beyond any doubt that a real broadband communication with PLC as last mile access technology is possible. The PLC infrastructure is delivering 4Mbps into the homes of Rooiwal Township [10]. The capabilities of PLC are unlimited and the continual PLC research in South Africa shows how experiences of using PLC can be adapted and be applied to business. These PLC research case studies allow government and organizations to relate to the PLC opportunity and unlock the true advantages of broadband PLC.

C. Advantages of Broadband PowerLine to South Africa

Power lines form one of the most extensive networks in the world, surpassing the phone network. Among the major strengths of PLC, the following are particularly noteworthy. Broadband PLC uses existing infrastructure, which allows a higher potential coverage than any other access technology [11]. Sending data over power lines can save the cost of building out a telecommunication infrastructure from scratch. Investments and operational costs are similar to xDSL and are even lower in cable services [12]. PLC second-generation equipment offer broadband services at transmission rates equivalent to or better than other access technologies. The technology has increased bandwidth up to 200Mbps with new functionalities [13].

Other than deploying PLC in non-broadband communities, implementation of PLC is also vital to South African Municipalities [11], which are currently losing millions in revenue due to theft and wastage of water and electricity. PLC, apart from its other sterling qualities, enables recovery of such losses. For example, a real-time automated meter reading function constantly monitoring the network to detect imbalances, and remote access to the meter will enable a 15-30% increased recovery in lost revenue [10].

However, PLC is not without other obstacles. The electrical supply networks are not designed for broadband communications and they do not present a favorable transmission medium. Thus, the PLC transmission channel is characterized by a large and frequency-dependent attenuation, changing impedance and fading as well as unfavorable noise conditions [4]. Various noise sources, acting from the supply network, due to different electric devices connected to the network, and from the network environment, can negatively influence a PLC system, causing disturbances in an error-free data transmission [13].

Recently though, new PLC technology has been developed that solved radio interference, low bandwidth, noise and loss problems associated with PLC, making PLC a viable option [2]. Broadband PLC research findings on interference have revealed that all these problems have been overcome. The technology has advanced so fast that in a short space of time of about three to five years, one can safely say that broadband PLC has been perfected. Apart from installations in over fifty countries across the world, a few installations in South Africa are currently running without problems [11]. The following sections present the experiments done at Forte Hare University on a PLC Network in comparison to the Ethernet Network as proof of the competitiveness of PLC Networks to other Broadband Networks.

II. OBJECTIVE OF THE EXPERIMENT

All these technologies are beneficial if their network bandwidths can be efficiently utilized by the network applications. Thus, it is important to conduct performance studies such as throughput measurements of the network applications executing over these networks. After designing the PLC topologies or any network topology, it is important to test these topologies under realistic traffic loads. While software simulations can provide valuable input in the investigation, it is crucial that the physical system be tested so that the actual network devices on that topology can be tuned. The experiments on the PLC topology in this paper utilize traffic patterns that closely mirror the expected user traffic load. The approach implemented in this research has proved beneficial in the comparative testing of the PLC Network and Ethernet Network under actual file transfer traffic loads.

This research made it possible to deduce the extent PLC networks can stretch in accommodating different traffic loads before the network performance is downgraded and the extent PLC network performance is comparable to fast Ethernet networks. As a result the study presents in the following sections the testbed topology and introduces the hardware and software configurations implemented in this research.

III. TESTBED EXPERIMENT HARDWARE

For the testbed topology investigation the descriptions and characteristics of the PLC elements or components utilized are briefly summarized here below. The commercial Mitsubishi PLC technology was selected as the testbed topology equipment and this technology support data, video and voice applications; in itself, it is an IP system [14]. PLC Mitsubishi is a 2nd Generation model that supports very high bandwidth of up to 200 Mbps over a distance of 300m, which exceeds 100Base-TX Ethernet category 5 enhanced transmissions of 100 Mbps over a 100m segment length. The Mitsubishi PLC technology package comprised the Frequency Division (FD) repeater which consists of two Time Division (TD) low voltage (LV) cards repeaters that are connected together to perform a FD transmission [15]. Its role was to regenerate the PLC signal for better coverage on the LV electrical grid and to relay communication between the adjacent PLC units. To ensure safe injection of the signal over the power grid capacitive coupling units (CCU) were used. CCUs are used to transmit/receive modem signals from the power lines and offer an inexpensive and easy installation solution which guarantee efficient signal injection without interrupting the energy flow of the electrical grid [4],[12]. At the user end there is the customer premise equipment (CPE), which is the user modem for a broadband connection, via the Ethernet interface. The CPEs are designed for home or office use, and are able to operate in single phase indoor distribution networks with 50 Hz mains voltage and they are presented in the diagrammed testbed topology in Figure 1.

IV. TESTBED EXPERIMENT SOFTWARE

All the experimentation on the testbed topology was executed and investigated utilizing the Open Source Software (OSS) Linux platform. Motivations for using Open Source Software are mixed, ranging from philosophical reasons to solid practical issues [16]. In this subsection, the practical reasoning of selecting the Open Source Software way is detailed. Traditionally the advantage of Open Source Software is that it is made available gratis or at low cost [16] thus making the testbed topology designed a cost effective solution. Besides expense cutting Linux brings in robust community built applications, to the non-broadband rural and urban communities of South Africa. A case in point is the Dwesa Cwebe rural community in which Fort Hare University, Telkom Center of Excellent (CoE) is demonstrating the applicability of Open Source Software in a rural setting, by researching and providing an OSS based e-commerce platform. In the end, this will alleviate the Digital Divide ("Digital Wall") that characterizes the Dwesa Cwebe rural community and South Africa at large [17]. The benefit regarding OSS is the capability to customize and tailor localized broadband services without being limited by licensing restrictions. In other words, this software is freely distributed under amicable licenses and it is less prone to ill-intention attacks. In regard to the goal of the CoE research platform and additionally for the reasons of cost effectiveness as maintained under this section, the Dynamic Host Configuration Protocol(DHCP) and the File Transfer Protocol (FTP) servers deployed in this research were all Open Source Software based.

A. Performance Investigation Using the FTP Application

The FTP protocol has been selected for our experiments because it constitutes what is considered the most commonly used network application [18] and is extremely likely that the use of this protocol has substantially increased in recent years. The FTP characteristics are briefly summarized in this subsection. FTP is a user-level protocol for file transfer between host computers on the computer network. Its primary function is to facilitate transferring of files between hosts, and to allow convenient use of storage and file handling capabilities of other hosts [19]. The objectives of FTP are to promote sharing of files (computer programs and/or data), encourage indirect use (without login or implicit) of computers, and shield the user from variations in file and storage systems of different hosts, to the extent that it is practical [18]. FTP operates in a client/server approach and uses two TCP port connections, one as a command channel and one for data transfer. A file is considered here to be an ordered set of arbitrary length, consisting of computer (including instructions) data. FTP does not restrict the nature of information in the file. For example, a file could contain ASCII text, binary data computer program, or any other information [19].

B. Downloading and Uploading Scripts Description

The FTP scripts (downloading and uploading scripts) that allowed the performance of the topology to be evaluated were developed using the Bourne Again Shell (bash) programming or shell programming, which is a Linux-based scripting language [20]. The use of bash programming has become a de facto standard for shell scripting on all flavors of UNIX systems. The scripts performed standard file transferring procedure from one machine on the PLC network to another with zero errors. The file size and time taken were parameters reported on each file transfer procedure, with a value of bytes per second, which is considered as one measure of network performance. This represented a measure of the throughput available to an application running on the network. In this research the developed FTP scripts proved useful and powerful as a measurement programs because they provided a way of quantifying how fast files were transmitted over the PLC Network and with such statistics, it was possible to make comparative analysis with the Ethernet Network.

The FTP scripts developed allowed the user to experiment with different file sizes parameters and in observe how they affect network performance. All server-oriented output was not sent back to the client, but remained at the server console. The same applied to the client-oriented output, which remained at the client console. This approach had the advantages that the implementation of the FTP server was relatively simple and the output of the client and server are independent making the scrutinizing of the FTP scripts output manageable. Therefore, the output was adjustable and more flexible to the wanted type of performance traffic.

These dedicated FTP scripts were developed also with an attribute of initiating automated multiple file transfer transactions from the different sources and to the same destination host in this case the FTP server. The advantage is that the result consumes less of the system resources and this feature is useful in following the FTP behavior across long connection paths. The scheduling of these multiple FTP streams was done using the cron mechanism, which is a powerful task scheduler present in the Linux platform that allows for the execution of commands at specified times. The configuration was set up to specify the time at which the required FTP script was to be executed. The cronjob timings were set at one-hour interval. The scripts recorded or measured time of the entire FTP data connection or transfer time. The scripts timed from the beginning of the connection to the completion of the data transfer on the client side. The scripts allowed the user to transfer files to and from the server while recording FTP transaction times and throughputs. The FTP server accepted commands from scripts files and because of this, the login process and the file transfer were automated. The uploading FTP script is the opposite of the downloading script and both scripts were capable of measuring the throughput of data transfer based on the transfer time that is the time required for transferring data.

C. Development of the Script for Specific File Size Creation

To have a better investigation and understanding of how sensitive the testbed topology was to file transfer, variable files with specific sizes were used. A file creation script was developed that created consistent files of specific sizes. This was done to investigate exhaustively how the designed PLC Network in comparison to the Ethernet Network reacts to file transaction processing as the file size increases. As a result it was possible to analyze the extent PLC Network would adapt to different traffic loads before the network performance was degraded. Also observed was the degree to which PLC Network performance is comparable to the other broadband networks in particular Ethernet Network.

After creating files, they were loaded to the FTP server where the FTP scripts were used to transfer the file across the network. At the same time monitoring the bandwidth usage of the FTP process as the files were transferred across the PLC testbed network from the FTP server to both the PLC client and Ethernet client. Besides using files as test tools for network performance, moving files across the network systems, is a powerful diagnosing tool that can help discover where a network problem resides in a network.

V. CHARACTERISTICS OF THE TESTBED

Figure 1 illustrates the configuration of the testbed topology with the PLC workstation connected to the PLC network and the Ethernet workstation connected to the campus LAN. The FTP server and the DHCP server were located in the Computer Science Masters Research Laboratory and both connected to the UFH Ethernet Network. The testbed topology was constructed in the Computer Science Laboratory at the University of Fort Hare using the commercial Mitsubishi Electric devices. We used traditional network FTP application as the basis for measuring PLC topology performance. The framework of the test environment used in these data transfer experiments consisted of two client computers running the Linux operating system and the other two computers were configured one as an FTP server and the other as a DHCP server respectively.

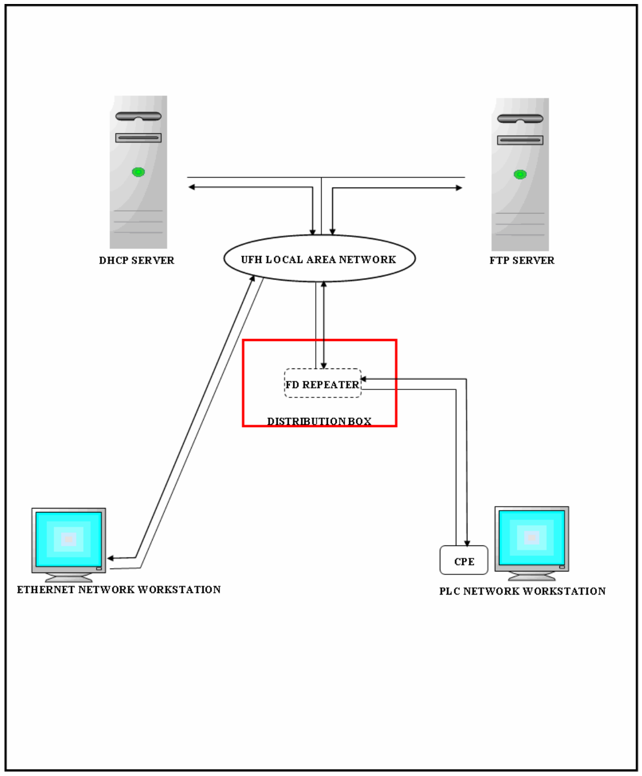

Figure 1 Testbed Set-Up

The CPE attached to the PLC client machine operated within an approximate distance of 5 meters from the FD Master in all the experiments. The testbed topology utilized a 5-meter segment of the Computer Science Laboratory. The FD Master was located in the same setting as the client computers and servers used in this experiment. This Laboratory is located in a University campus environment and other operating computers and peripheral devices shared the same electrical main with the testbed topology during the experiments. The FD Master was connected on one side to the University Ethernet Local Area Network and on the side coupled to the Laboratory electrical grid, thus it converted packets generated from the Ethernet network into PLC network compatible packets, and vice versa.

VI. EXPERIMENTS AND RESULTS ANALYSIS

In the experiments, ten files were provided using the file creation script and tested separately. Two clients (PLC and Ethernet) are simultaneously used to fetch a specified file size from the FTP server. The resulting measurements or the transfer statistics produced by the FTP script were used to depict the behavior through graphs. The FTP script produced transfer time and transfer speed as output which together with throughput were plotted against file size as shown in the figures 2, 3 and 4. During the tests, it was ensured that other machines sharing the Ethernet Network do not generate considerable traffic while experiments were being conducted.

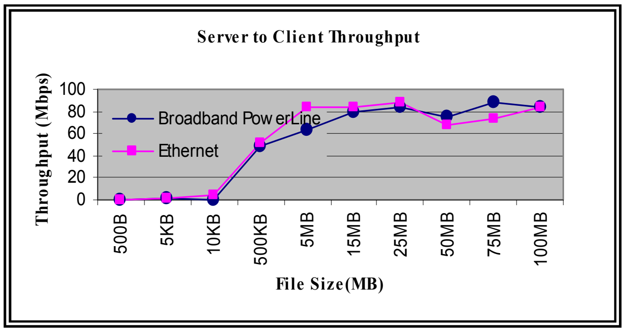

Figure 2: Throughput achieved by both Clients

In the server to client direction Figure 2, the PLC Network client achieved higher throughput for large files (from 500KB) but slightly lower throughput for the smallest file (500B). The Ethernet Network client had a slight drop in throughput on the 50MB, 75MB and 100MB. The PLC Network Client slightly outperformed the Ethernet Client on the 50 MB file and 75 MB file mark but it had a drop on 5MB file as shown in Figure 2, but in general both systems exhibit similar performance. The peak throughput is observed with the 75MB file size on the broadband PLC network.

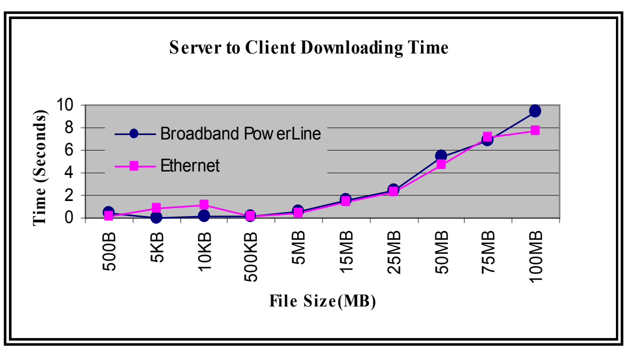

Figure 3: Time taken by Clients during File Retrieval

On the time taken versus file size in Figure 3 both clients, show an upward trend with Ethernet client achieving the least time in retrieving the largest file. However, both clients show similar improvement without marked differences.

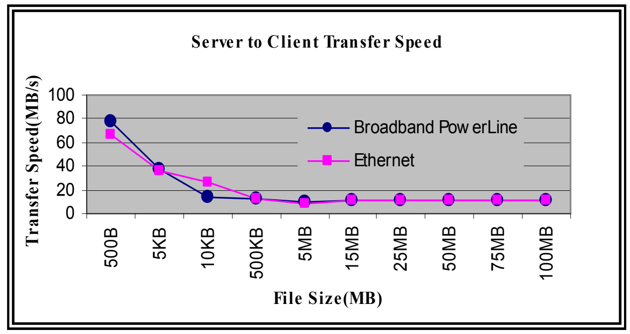

Figure 4: Transfer Speed achieved by both Clients when Transferring Files

In Figure 4 the transfer speed, show a gradual decline, decreasing from the smallest file to the largest file. PLC client had a high transfer speed on the smallest file. Both clients had a more or less similar trend. These results confirm the normal trend of increased throughput towards the link bandwidth with larger packets, especially with little across-the-room round trip time (RTT).

VII. CONCLUSIONS

A. Deductions on the Experiment

The main consideration of this research was the throughput achieved by the FTP application operations over the testbed network. Despite the constraint imposed by the file systems, the FTP experiments demonstrated significant comparability and competitiveness of PLC Network to the Ethernet Network. It must be noted that the contention and noise by other devices on the Ethernet and PLC network had effect on the transfer speed, transfer time and throughput. Though PLC Network had low throughputs, low transfer speed and high transfer time on some files it proved and compared well to Ethernet. PLC yielded improved throughputs without marked difference or much gap from those depicted by Ethernet. Furthermore, PLC transfers were always at a near constant rate with very little fluctuation. The resulted throughputs depicted by PLC Network are adequate to execute applications just as in the conventional networks such as the Ethernet Network. The overall results show that PLC Network has capability for reliable connection service and throughput performance comparable to Ethernet Networks.

Also, considering PLC coverage of 300m in optimal power lines conditions, the use of directional signal filters [7] in combination with FD repeaters will increase the scalability of a PLC network, enabling it to span Ethernet LAN coverage. PLC then could play an important role in providing access networks to offices and residential areas. Though the cost of implementing is becoming cheaper, it must be acknowledged that the relevance of PLC to non-broadband communities without electricity is limited. Additional studies and more extensive testing are currently under way in multi-building conditions at Fort Hare University. These facts imply that though PLC is relatively recent in the broadband mainstream, it has the capacity to deliver broadband to the non-broadband communities in South Africa.

B. Summary on Digital Divide and Broadband Delivery

In summary, for Southern Africa and in particular South Africa to make a difference in Broadband Delivery to the non-broadband populations, South Africa and the involved organizations must coin definitions for broadband to impact Broadband Delivery, thus reducing the abuse of the term broadband. Open-mindedness of South Africa and the research organizations to research and experiment with new solutions with constructive criticism will go a long way for South Africa.

Regarding Digital Divide ("Digital Wall"), broadband is not the only solution that will bridge the gap (or pull down the "Digital Wall") between the haves and the have-nots. Extensive intervention is immensely required from the government of South Africa. Technology by itself will not change the lives of the disadvantaged. For that to happen there is need for solid commitment from government, and that obligation must run from top to bottom. Without significant policy leadership, access to broadband will remain the domain of the advantaged broadband communities in South Africa [1]. The high penetration of the electrical power grid in rural South Africa is an opportunity to integrate PLC in a global effort for "Broadband for All".

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