PROSPECTS OF THE VERY HIGH SPEED DIGITAL SUBSCRIBER LINE TECHNOLOGY IN AN EMERGING ECONOMY: NIGERIA AS REFERENCE

BY

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ABSTRACT

There has been a steady increase in demand for digital services provided over the public telephone line networks worldwide since the discovery that these plain old telephone lines can support voice as well as data transmission. This paper describes the vast potentials of the very high speed digital subscriber line (VDSL) technology abounding in an emerging economy like Nigeria. The evolutions of xDSL technology are also described as well as the technology of the VDSL systems. The applicability and transmission environment of the system and the various impairments to the VDSL systems are studied. Mitigation techniques to combat these impairments are also overviewed.

Introduction

Digital subscriber line (DSL) technology is basically used for the transmission of digital information by means of copper wire pair (usually untwisted pairs). This transmitted information though in digital form, but the transmission medium is often an analog carrier signal or its combination, modulated by the digital information signal.

In earlier times, the telephone access network was originally constructed at a large scale primarily for voice band telephony. These Plain old Telephone Systems (POTS) were built using inexpensive cabling with high reliability and capacity covering a very large population at relatively low cost. Because of its simplicity and usefulness, the infrastructure has grown to be one of the most valuable assets in many countries, Nigeria not being an exception.

The POTS wires were only used for telephony (voice band transmission), the frequency being from (0-4KHz). However developments in modern electronics made it possible to realize that these copper pairs can also be used for other types of directed communications at low cost. Thus the emergence of telegraph, fax machines, and computer modems, these technologies easily transmit and receive information (data) bi-directionally between any two places using the ordinary telephone system. Also interconnectivity between communicating devices are easily and cheaply established via these copper pairs. Replacing the low pass filters at the telephone stations and installing digital subscriber line (DSL) modem, the spectrum usage of the twisted pairs can be tremendously increased up to tens of megahertz as against the (0-4KHz) initially offered by POTS. This increased frequency range provides data transmission rates that a factor (1000) higher than the fastest voice band modems can offer. Figure 1 below gives a general view of the DSL technology.

This paper looks at the prospects of the deployment of the VDSL technology in an emerging economy and the potential benefits this technology could offer to such economy with strong reference to Nigeria.

Section 2 looks into the evolutions of the DSL technology, the impairments and challenges hindering its full deployment are explored in section 3. Section 4 focuses on the prospects and potentials of this technology. And finally, conclusion is made in section 5.

The xDSL is drawing significant attention from implementers, and service providers because of its potential to deliver high-bandwidth data rates to dispersed locations with relatively small changes (low cost) to the existing telco infrastructure. These services are dedicated, point-to-point, public network access over twisted-pair copper wire on the local loop between a network service provider's central office and the customer site.

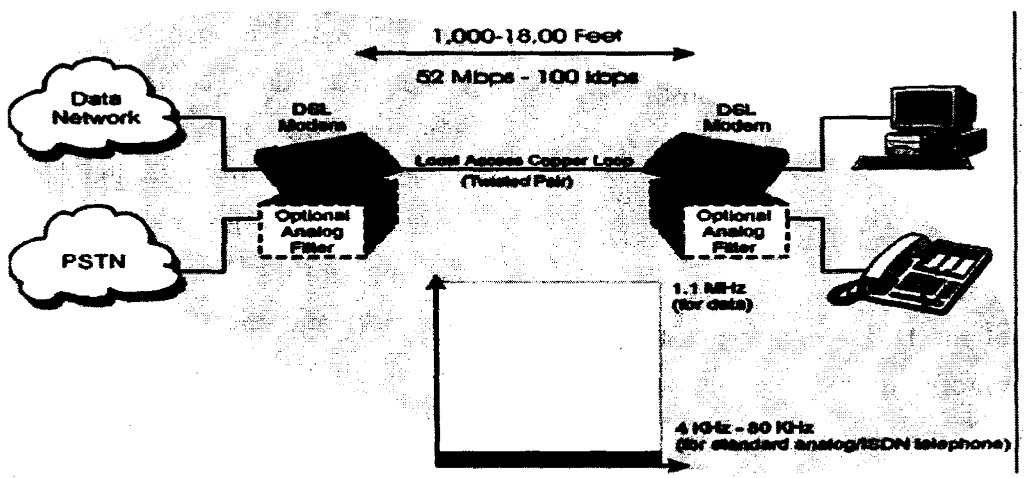

Figure 1: The Outlook of DSL Technology

Evolutions of the DSL Technology (THE xDSLS)

The DSL has evolved greatly over the years; it was first used in the 1960's to describe the

T-1 circuits which were extended to the customer premises.

Integrated Digital Services Data Network (ISDN)

However, it was introduced as a service (technology) according to in (1986) as the Integrated Service Digital Network (ISDN). This offered a total symmetrical data rate of 160Kb/s (to-from the customer) data rate over loops of up to about 4.5km. The data rate was divided into two 64kb/s channels for data and two 16Kb/s channels for signaling and line control.

The evolution picked in the 1990's with advances in new modulation technologies, digital signal processing circuits, these advances thus increased the data transmission capability of twisted pair copper wires to over 50Mb/s. it should however be noted that not all accept that ISDN is a variant of the xDSL systems.

Each of the DSL technologies usually has a prefix to indicate the specific variant of DSL technology. Thus, the "x" in xDSL indicates the many forms of the DSL technology.

The High Speed Digital Subscriber Line (HDSL)

Because of the need for high speed data transmission and the complex circuitry of the first version (T-1) system, a new High-speed DSL (HDSL) technology was developed. This thus increased the distance that high speed digital signals could reach. This system required 2 or 3 pairs of wires to allow simultaneous (send and receive) of up to 2Mb/s of data transmission. This system's drawback is the number of copper pairs required (2/3). In order to reduce the copper-pair needed for data transmission, the Symmetrical Digital Subscriber Line **SDSL** evolved. The SDSL offer lower data rates however, but require fewer copper-pairs (2). This is followed by the development of the **HDSL 2** that allows data transmission via 2 wires only for duplex transmission, with reduced emissions.

Asymmetric Digital Subscriber Line (ADSL)

ADSL is a popular means to connect private branch exchange (PBX) and packet/ATM data equipment to the public network. They are used to link wireless radio sites into the landline network. As the name implied (asymmetric) the downstream (towards customer) and the upstream (towards network or CO) transmission rates are different unlike the symmetric DSL previously analyzed. The Asymmetric Digital subscriber lines systems ADSL evolved as a result of new efficient modulation technology to dramatically increase the data transmission rates to over 6Mb/s-8mb/s from the central office (CO) to the customer. The ADSL concepts evolved during the early 1990's

This technology transmits data via the POTS with

- Downstream bit rates up to about 9Mb/s and
- Upstream bit rates of up to about 1Mb/s

Analog voice is transmitted at baseband frequencies and combined with the pass band data transmission through a low-pass filter commonly called splitter. Many versions of ADSL were later standardized out of the ADSL 3 concept. This standard is issue 1 ANSI T1.413 ADSL standard.

Rate Adaptive Digital Subscriber Line (RADSL)

The RADSL is referred to as ADSL technologies capable of automatically determining the transport capacity of the individual loop and operate at the highest suitable rate for the local loop. The ANSI T1.413 standard provides this capability for rate-adaptive operation. The RADSL concept originated from rate adaptation from voice-band modem. Thus RADSL assures the highest possible transmission rate for each local loop and also permits operation on long loops at lower rates.

ADSL provides the access technology needed by Asynchronous transfer mode (ATM) to open the door to home and small office connectivity. These technologies are currently being developed to convey multiple digital derived voice circuits in addition to high speed data.

Very High Speed Digital Subscriber Line (VDSL)

Very-high-bit-rate Digital subscriber lines (VDSL) technology provides tens of megabits of data per second to customers who desire broadband data services. VDSL systems transfer both analog and digital information on a copper-wire pair. The analog information can be the standard POTS or ISDN signal and the typical down-stream digital transmission rate vary from 13 Mb/s to 52 Mb/s. The up-stream data rate can be up to 26 Mb/s. the rate of data transmission is a function of: the distance, VDSL settings from the service provider, and line distortion. The maximum practical distance for this system is about 4,500 feet. However 52 Mb/s is only possible for lengths usually less than 1,000 feet.

VDSL is basically used for loops fed from an Optical Network Unit (ONU) typically located less than a kilometer to the Customer, only a few is served directly from the Central Office (CO)..

The figure 2 below captures the xDSL evolutions graphically.

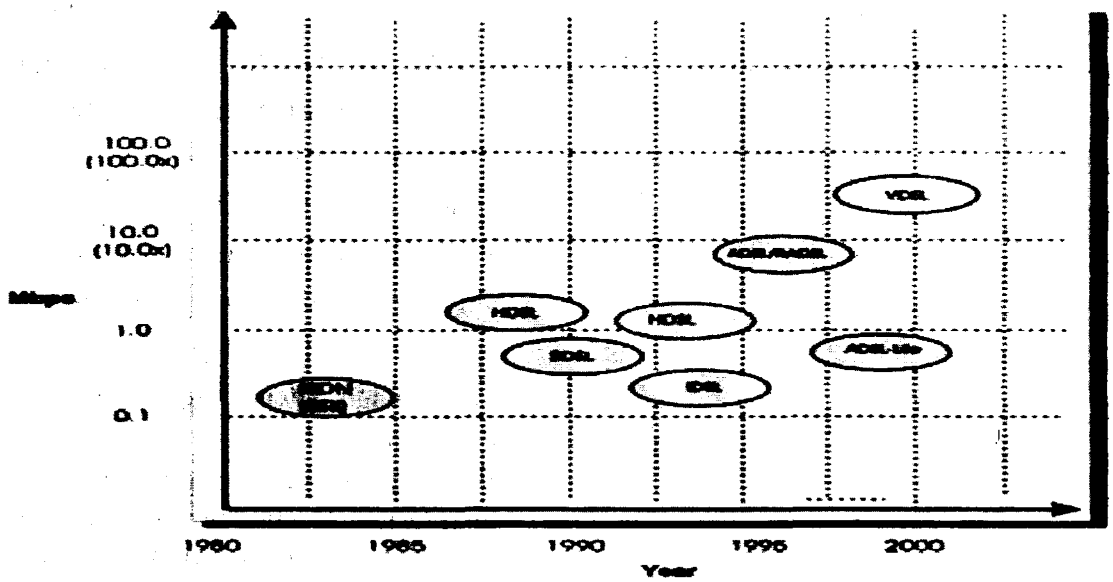

Figure 2: XDSL Evolutions

Fiber loop carrier systems are used to bring the high band width promise of fiber closer to groups of hundreds of phone company customers served by the optical network unit (ONU). From the ONU, two pairs emanate and link the customers thus completing the path that began with fiber to the ONU. Sometimes direct connections of the twisted pairs from the customers to the CO are done with much power expended. The splitter makes it possible for the ordinary phone services to remain unchanged to the customers. This system accounts for about 15% of the American population, and a smaller percentage in most other countries.

Data Transmission

VDSL is basically different from other xDSL transmission technologies because of its capability to deliver extremely high data rates. This thus enhances simultaneous transmission of many different services to-and-from the customer over a single link (VDSL link). ATM-enhances this feature of VDSL system when it serves as the transport layer, providing universal transport capability for all types of services including synchronous data services with constant bit rates e.g. digital video, packetized data application with variable bit rates like IP.

This thus takes full advantage of ATM implementation

- ❖ Access interfaces are independent of offered services

- ❖ Provisions and managements of many services over a single network infrastructure, thereby simplifying network operations.
- ❖ Delay-sensitive services like voice, interactive video are supported
- ❖ Service evolution from existing to new broad band services is ensured

Impairments of VDSL

The unshielded twisted-pairs (copper cables) were constructed originally to support services limited to the voice band spectrum. There exists a number of impairments in using this transport medium for higher frequencies as is applicable in VDSL-modems. Each subscriber loop consists of a pair of insulated copper wires with a gauge between 0.4mm to 0.9mm. This insulation is PVC or polyethylene though it used to be paper insulation.

These impairments can be broadly classified as being intrinsic or extrinsic to the cable environment according to (Cook, 1999).

Intrinsic noise impairments are: Thermal noise, echoes and reflections, attenuation, and cross talk. Some components making up the cable infrastructure that can impair operation include: surge protectors, radio frequency interference (RFI) fitters, loading coils, and bridged taps etc. Extrinsic impairments are: Impulse noise, radio frequency interference (RFI).

The VDSL transmission environment

These VDSL lines usually can run from the CO, or from the ONU to the customer. This is as shown below in figure 3

.Figure 3: the VDSL technology

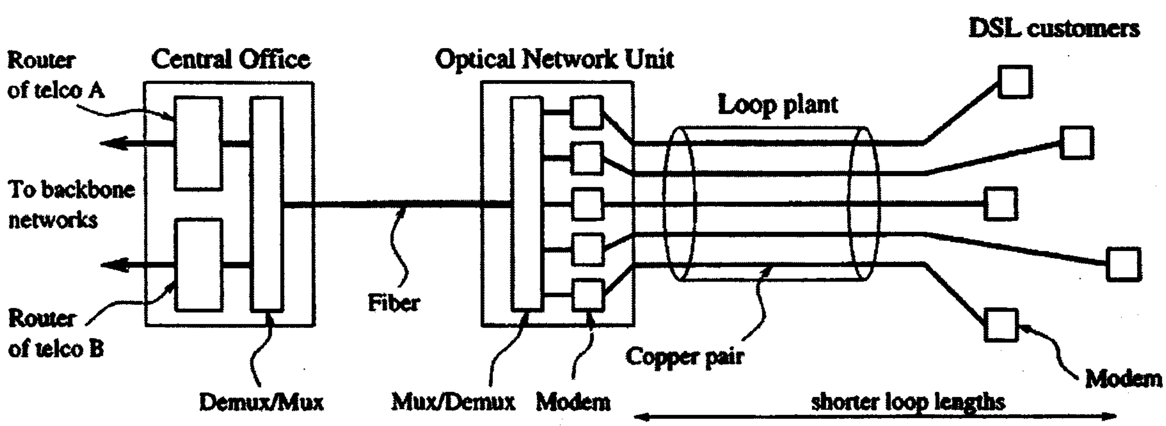

Figure 3: The VDSL Technology

These copper pairs are usually unshielded and twisted, and of 24- or 26-gauge twisted pair type, which could be aerial or buried. Multiple telephone (VDSL) pairs often share the same cable. Sometimes bridged taps are inserted to create access to other phones or service points. The splitter devices are used to separate the VDSL bandwidth from that of the normal POTS bandwidth that range from 0-4 KHz.

Crosstalk

The dominant impairment in DSL technologies is crosstalk arising from electromagnetic coupling between neighboring twisted pairs. The crosstalk loss parameter is defined as the attenuation experienced by a disturbing signal while passing through the coupling mechanism before arriving at the disturbed receiver.

Basically crosstalk is of two types: The Near End Crosstalk (NEXT) and the Far End Crosstalk (FEXT).

NEXT describes the coupled signals originating from the same end as the affected receiver. This can be said to be the interference that appears on another pair at the same end of the cable as the source of the interference. Its level is mostly independent of the cable length (Cook, 1999). It affects systems that can transmit in both directions at simultaneously. It is primarily as a result of signals traveling in opposite direction. This is shown in the figure 8 below.

FEXT is said to be the interference that appears on another pair at the opposite or far end of the cable source of the interference. Its level is attenuated as the length is increased, at least to the level that the transmitted signal is attenuated over the same length. FEXT is as a result of signals traveling in the same direction. This is also shown in the figure 4 below.

Figure 4: NEXT and FEXT crosstalk.

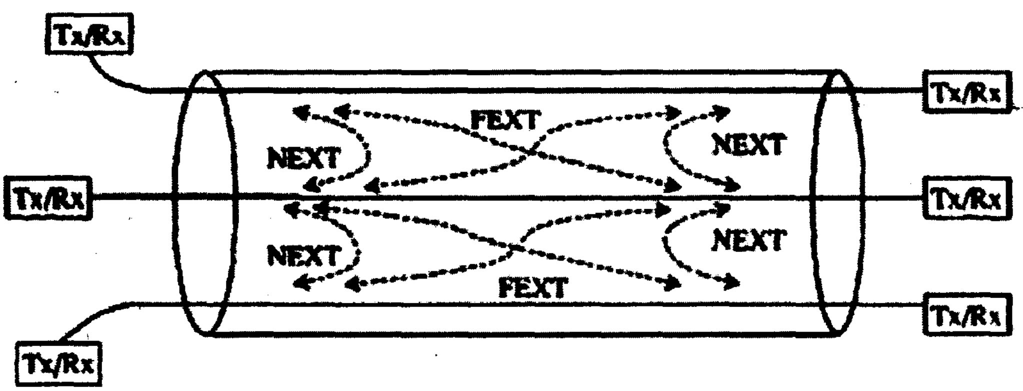

Figure 4: NEXT and FEXT Crosstalk

Capacitive and inductive imbalances and couplings are the main sources of crosstalk in cables (Lafata, and Vodrazta, 2011)

Near echo is similar to NEXT, and occurs between the transmitter and receiver part of the same modem due to imperfections in the hybrid that separates the downstream and upstream signals.

The spectral density of FEXT and NEXT are derived from the transmission line theory.

The NEXT-PSD from a source with PSD S(f) is modeled by

$$S_{next}(f) = K_{next} f^{1.5} S(f).$$

Where $K_{next} = 10^{-13} (N/49)^{0.6}$ is a constant obtained from empirical studies.

N is the number of pairs in the same binder that carries the same VDSL service.

The FEXT – PSD is modeled also as

$$S_{fext}(f) = K_{fext} f^2 d\,|H(f,d)|^2 S(f).$$

Where $k_{fext} = 3.27 \times 10^{-19} (N/49)^{0.6}$

It is observed that the NEXT is independent of cable length but increases with frequency. Increasing N, crosstalk contributions from many lines add, and the NEXT and FEXT tend to be Gaussian distributed due to the central limit theorem. Alien crosstalk is crosstalk that originates from other services which may be present in the cable. Example, VDSL systems may encounter alien crosstalk from other DSL services and POTS.

Radio Frequency Interference (RFI)

Transmission over the twisted pair line is carried in the differential mode (DM), such that the current in one wire is balanced by an equal but opposite current in the other wire. Coupled with the twist, the electromagnetic fields between the two wires cancel almost completely. The common mode (CM) voltage is the mean voltage between both wire pairs and the ground, and should be as low as possible. The unshielded wire acts as a large CM antenna capable of radio frequency – reception (ingress) and radiation (egress). Radio frequency interference is ingress noise introduced from radio transmitters operating in the vicinity of unshielded twisted pairs. Amateur radio transmitters operating in the so called HAM bands and AM radios that operate in the same frequency bands as VDSL are typical examples. Since the twisted pairs are either aerial or buried this ingress to an aerial is about 10dB higher than that for a buried pair, though this varies. Much work has been carried out on this subject; see (Foster, 1996) and (Foster, and Standley, 1996) The table below shows typical amateur radio bands near the VDSL frequencies capable of causing ingress.

Table 1

HAM Bands (MHz)								
	Low	1.81	3.50	7.00	10.10	14.00	18.068	21.00
	High	2.00	4.00	7.10	10.15	14.35	18.168	21.45

Impulse Noise

This is a non-stationary interference as a result of short lived electromagnetic fields in the region of the twisted pairs. It is usually a temporary signal that is either narrow-band or wideband and its occurrence is random and highly unpredictable. It can be caused by a variety of electronic, electromechanical devices, lightning strikes on witching equipment, power line transients.

A widely used analytical model of an impulse as obtained John Cook; called the continuous time cook pulse model is:

$V(t) = V_p|t|^{-3/4}\,\mathrm{sgn}(t)$

Which is discontinuous at t = 0 and with infinite energy. A sampled version of this with

t = nT and V(0) = 0 become more reasonable with a peak value of $V_p/T^{3/4}$.

Impulse noise can be tens of millivolts in amplitude (5-20mv) is typical, and can last as long as hundreds of micro seconds (30-150μ) is typical, its spectral energy is concentrated within 40 KHz, and occurrence rate of (1-5) pulses per minute.

Crosstalk mitigation

Cross talk is by far the most pronounced of all the impairments to the DSL systems and there are many approaches deployed to greatly reduce this impairment. Some of the prevailing techniques are briefly discussed.

The use of twisted pair, end-to-end grounding and systematic separation of the directional channels (duplexing) into discrete frequency bands and time domains are some of the mitigation techniques against crosstalk (Foster, 1996). Thus the impact of NEXT from same systems is suppressed by employing frequency division duplexing (FDD) to separate the downstream and upstream transmission. Self FEXT is the major performance constraining factor especially at shortened loop lengths. Though narrower, the self FEXT is effectively reduced by a technique referred to as vectored transmission or vectoring (Ginis, and Cioffi, 2002). This technique treats the channel as a multi-input/multi output (mimo) system and employs joint signal processing of all signals at either the receiver side (for upstream transmission) or at the transmitter side (for downstream transmission).

Other methods deployed to mitigate crosstalk in VDSL environment are.

Decision Feedback Canceller (DFC); though this increases in complexity as the number of active user in the binder increases (Cendrillon, 2006). Also the DFCs performance is good usually under white noise conditions (Cendrillon, 2006) and (Gujrathi, 2006).

Normalized Least Mean Square (NLMS) adaptive technique; works through estimation of a suitable crosstalk cancellation matrix. This approach has low complexity compared to DFC and needs no additional processing if the noise is colored or the noise statistics are varied. The drawback here is the slow convergence rate of the NLMS algorithm, especially in system with a large number of estimation parameters. A wide band cancelation approach for crosstalk interference cancelation was proposed by (Kamkar-Parsi, 2004).

Prospects of VDSL systems in Nigeria

As at 2006, the total number of DSL lines in Nigeria was about 500,000 (half a million). This number served an enormous population of 140 million. The ratio is about 1 DSL system to 280 people, which is greatly inadequate. This figure depicts the large potential existing in the Nigerian market for this technology. This present scenario in as a result of the fact that the telecommunication sector in Nigeria though privatized, is yet to take advantage of the promises of this VDSL technologies to deliver; data, voice video etc to customers. This is mainly because of the bureaucratic bottle neck in the privatization of the government owned telecommunications company (NITEL) which owns about all the deployed DSL lines in the country.

As an access technology that can work over existing non loaded phone lines, providing high speed asymmetric (and symmetric) digital delivery without disrupting normal voice service, and that is economically attractive through the use of sophisticated but highly integrated signal processing hardware presents a powerful vehicle for making new services available to residential customers. The promise of the VDSL technology that appeals to operators and subscribers (customers) alike are:

- Offering of very high speed data transmission rates up to 52mb/s
- Reduction in cost as it uses the already existing the POTS infrastructure
- Capability to transmit voice,

data, video etc over the same twisted copper pair channel

- Interference mitigation since the transmission is a digital form.
- This technology can be programmed to carry symmetric mode (data networks or LAN extensions) mostly for business premises or asymmetric mode (Internet web surfing or TV).
- VDSL systems support video conferencing, telemedicine, distance learning, home shopping, are entertainment etc.
- Multimedia: The personal computer industry has aggressively pursued "multimedia," in which all of the best attributes of graphics, video and compressed high fidelity audio are used simultaneously to enhance interaction with the application. As multimedia capabilities become more sophisticated and of higher fidelity, the advertising industry is becoming more interested in the medium. Advertising coupled with next-generation applications could help to defray costs of offering new services, bringing them within reach of the mass market.
- Education and video on demand: For example, there may not be enough demand at one High School to hire a specialized teacher, say in foreign language or advanced calculus. But if one specialist teaches students throughout several of such schools by way of 1.5 Mbps or more rate video, the economies are much more attractive and the quality of education is improved.

Conclusion

The very high speed Digital subscriber line (VDSL) is the latest transmission technology for data transmission on the twisted pair phone lines or POTS. It allows data rates from a few hundred kilo bits per second on long phone wires to tens of megabits per second on shorter lines. Thus the data rates are functions of distance. The impairments to the VDSL systems like Crosstalk, RFI and impulse noise pose a challenge to this technology. Some of the approaches used to mitigate these impairments have been studied. This makes for a sophisticated adaptive design of the systems. The promise and prospect of this technology in an emerging economy like Nigeria is also studied. This technology might fulfill the ultimate promise of the simple twisted pair invented by Alexandar Graham Bell. The VDSL will definitely have a positive impact on any emerging economy as Nigeria or even on developed economies.

Recommendations

The already laid down fiber optic cables and the supporting technology hitherto lie underutilized, and the current copper twisted pairs wires wasting and deteriorating since most are non functional as a result of the current condition of the service provider (NITEL). Reviving this technology will have a wide reach and positively impact on the way people do business, transmit and receive information and interact both locally and globally.

The promise and potential of VDSL technology is rich and vast in Nigeria and in view of the above mentioned potentials of the technology, the following recommendations are made:

- ❖ That the federal government should as a matter of urgency fast track the privatization of NITEL.
- ❖ Creation of conducive environment that is private sector driven.
- ❖ Reduction in the cost of operating license to make room for healthy and competitive market.
- ❖ The government should be at the forefront in the deploying and revival of this technology as it is cheaper and readily available

KEYWORDS: VDSL, Data transmission, Twisted-pair, Technology, Crosstalk, Impairment.

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