Power Line Communications: A Platform for Sustainable Development

Matthew Kwatri Luka
Department of Electrical and Electronics Engineering
Modibbo Adama University of Technology, Yola
matthewkl@mautech.edu.ng

Felix Olowononi
Department of Electrical and Information Engineering
Covenant University, Ota
felix.olowononi@covenantuniversity.edu.ng

Joseph Stephen Soja
Department of Electrical and Computer Engineering
Ahmadu Bello University Zaria, Nigeria
sojasteve@gmail.com

Abstract –**Electricity infrastructure together with information and communication technology (ICT) constitute a veritable platform for driving inclusive and sustainable development. However, last mile internet access in underdeveloped areas is limited by deficit telecommunications infrastructure. This is mainly due to the cost associated with deploying telecommunication distribution networks and the low returns on investments associated with underdeveloped areas. The availability of electric power grids which can be used as telecommunication distribution networks, makes the idea of using power line communication and wireless networks a realistic means of providing communications service to underdeveloped areas.On the other hand, electricity utilities needs an efficient and cost effective means of operating and managing the electric grid. This paper reviews different power line communications technologies that can used to achieve a smart grid model that provides a sustainable electricity and ICT infrastructure for development in Africa.**

Keywords—Narrowband Power Line Communications, Broadband PLC, Broadband Internet Access, Smart Metering, Electricity Theft Prevention.

I. INTRODUCTION

Modern power grids have evolved from a vertically integrated system to an unbundled system that introduces market activities at the generation and distribution ends. To this end, power utilities have been split into various independent entities of generation companies (GENCOs), transmission companies (TRANSCOs) and distribution companies (DISTCOs). This unbundling allows the integration of large scale sustainable and renewable energy sources and improved competition. However, the introduction of distributed energy sources can result in islanding due to power failure. It is thus necessary to incorporate robust communication technologies that ensures the security and stability of distributed utility system [1].At the distribution end of the power system, smart grid offers a platform for advanced metering infrastructure, demand response and demand side management. These applications enables DISTCOs to reduce both technical and non-technical losses as well as encourage active consumer participation in the management of the power system. Smart grid involves the use of various communication technologies to provide the needed monitoring, control protection.Generally, the communication system of a power system can comprise of satellite, the internet, fixed networks (e.g optical fiber) and wireless networks (e.g WiMAX and GSM). These technologies are inadequate or in some cases unavailable in underdeveloped areas. Even where these communication infrastructures are available, the cost of renting is not justified. Another important parameter that influence the choice of smart grid technology is the wiring topology and power distribution infrastructure of an area or utility. Wireless technologies are better suited to electric distribution infrastructures that relies on small transformers to serve small number of homes [2]. On the other hand, technologies that allow aggregation of user information are more amenable to distribution infrastructures that utilize large secondary transformers to service a several homes. Power Line Communication (PLC) isa suitable and cost effective means of achieving smart grid in in underdeveloped areas where most conventional communication systems are not available. PLC is suitable for the wiring topology and power distribution infrastructure of most African countries where large secondary transformers which serves several homes are used. The use of fewer but large transformers minimizes attenuation of the PLC signal by transformers. A number of smart grid projects based on PLC have been implemented in Europe, where the power distribution topology is similar to that of most Africa countries [3], [4]. PLC technologies operating below a frequency range of 500 KHz are known as narrowband technologies. Narrowband technologies can be employed for various *energy-related* services such as automated meter reading, dynamic pricing, distribution system monitoring/maintenance, demand side management etc. Narrowband technologies are also used for automation of building systems and electric devices as well as implementing security task and sensor interconnections.

In addition to using PLC technologies for sustainable management of the electric grid, they can be used for providing telecommunication services. Telecommunication access networks are used for providing direct connection to subscribers. However, it is estimated that about 50% of all telecommunication investments is expended in the realization and management of access networks [5]. This impedes investment in access network infrastructure due to slow return on invested capital especially in rural/underdeveloped areas. Broadband PLC technologies can be used to realize a cost effective access network as it leverage the existing electric power distribution system.Broadband PLC technologies operate at frequencies above 1 MHzwhich can support broadband internet access, multimedia services and utility application with adequate quality of service (QoS). Broadband technologies can

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also be used for In-home applications such as setting up a local area network (LAN) and home automation and security tasks. Connection to individual endpoints over the low voltage (LV) distribution network is known as Home Area Network (HAN). Neighborhood Area Networks (HANs) are implemented over the medium voltage (MV) segment of the distribution network to provide an interaction point between HAN and the utility's operations network. In NAN, data concentrators are used to aggregate information from various endpoints for transmission to utility database/information system. PLC technologies finds more extensive application over HAN and WAN, partly due to the distributed nature of modern communication system and the significantly high attenuation over the high voltage segment. Narrowband technologies cannot support the high data rate of aggregated user data over the WAN. On the other hand, broadband technologies cannot by-pass transformers due to the inductive nature of transformers and the increase in attenuation with frequency. Other communication technologies such as WiMAX, GSM, satellite and optical fiber networks offer better alternatives for implementing smart grid over the WAN. The cost of renting or installing conventional technologies for WAN is justified due to the large bandwidth of aggregated user information from the HAN/WAN. However, PLC technologies can be used over the HV segment to implement low data rate system wide monitoring, protection and control. Section II of this paper provides an overview of both narrowband and broadband PLC technologies. Grid management applications necessary to ensure a sustainable electricity infrastructure are highlighted in section III. Section IV provides disquisition on some ICT services that can be realized using PLC technologies.

II. PLC SMART GRID ACCESS SYTEM

The concept of PLC began with the deployment of carrier frequency systems (CFS) on HV line for voice communication and operations management. CFS operate in the 15 – 500 kHz frequency range and is capable of achieving a coverage distance of up to 500 km with an average transmission power of 10 W [6]. However, CFS was not amenable to LV and MV distribution networks due to different conductor types and the high number of inter-connections. Ultra narrowband (UNB) technologies such as the turtle system, ripple carrier signaling (RCS) and the two-way automatic communication system (TWACS) were developed for use on the LV and MV segments. These technologies operate between the super-low frequency band (30 – 300 Hz) and ultra-low frequency band (300 - 3000 Hz) and provide low data rates of few bps. The power requirements of UNB systems (between 10 kW – 1 MW for RCS) is asignificant cost factor. The need for higher data rate and low transmission power motivated the development of low data rate (LDR) narrowband technologies. The CENELEC EN 50065 (Comite European de Normalisation Electrotechnique) is a popular standard for LDR narrowband technologies. The percentage of bandwidth reserved for various application in the CENELEC standard is shown in Fig.1.

LDR narrowband technologies such as LonWorks (ISO/IEC 14908), KNX (ISO/1EC 14543-3-5), IEC 61334-3-1/IEC 61334-5 and CEBus (CEA-600.31) are based on single-carrier or spread spectrum transmission technologies. As depicted in Fig. 1, much of the bandwidth is reserved for energy related services, leaving only 38% for other smart grid applications. To provide more bandwidth for other smart grid applications high data rate (HDR) narrowband technologies with operating frequency of up to 500 kHz were developed. These technologies also employ the use of Orthogonal Frequency Division Multiplexing (OFDM) for improved resiliency against frequency selective fading and attenuation associated with the power line medium. Current OFDM based narrowband technologies include the ITU-T G.9902 (ITU-T G.hnem), ITU-T G.9903 (G3-PLC), ITU-T G.9904/PRIME Powerline Related Intelligent Metering Evolution) and IEEE P1901.2 standards [7]. As outlined in [2], the data requirement of smart grid applications ranges from few bytes to tens of kilobytes. However, modern smart grid applications such as advanced metering infrastructure (AMI) may comprise of millions of nodes. The sheer size of nodes may result in difficulties in real time data delivery, downstream data flow and realizing certain functions (such as firmware upgrade) that may require higher data rates. There are a number of broadband narrowband technologies such as IEEE 1901(HomePlugAV/HD-PLC), ISO IEC 12139-1, ITU-T G.hn, HomePlug AV2, HomePlug Green PHY, UPA Powermax, Gigle MediaXtreme and TIA- 113/ HomePlug 1.0 that can be used to implement high data rate smart grid and in-home applications with satisfactory QoS characteristics.

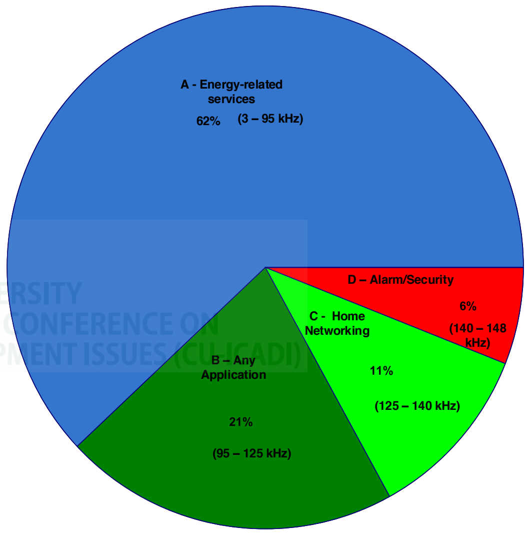

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Fig. 1 CENELEC EN 50065 PLC Band plan

A. *HDR Narrowband PLC Access Networks:Architecture and Topology*

The HDR narrowband technologies can be used for both In-home network and as access network especially for utility metering infrastructure. The access network of the different technologies have a number of difference in network formation, security profiles, frequency bands of operation and routing techniques used.IEEE 1901.2 standard is based on an OFDM PHY and an IEEE 802.15.4 MAC layer. Although the standard was derived from the G3-PLC standard, it does not specify functionality for a number of higher layer processes such as routing, collision avoidance mechanism, bootstrapping techniqueetc.[1], rather support for these functionalities is supported through Adaptation layer Service Access Point (see annexes of [8] for implementation guidelines and examples) . An IEEE 1901.2 network is formed, maintained and controlled by a Personal Area Network (PAN) coordinator. Access to the power line media is controlled using unslotted CSMA/CA (collision sense multiple access with collision avoidance) for non-beacon PANs and slotted CSMA/CA for beacon PANs. An L2 or L3 routing algorithm can be used to create star, mesh or tree network topology; depending on the application. The 1901.2

standard supports indoor and outdoor communications for the following scenarios[9].

- Communication over low voltage line (less than 1000 V); the power line between meter and transformer
- Across a transformer low-voltage (1000 V) to a medium-voltage (72 KV) and vice versa in both urban and rural communications
- Lightening and solar panel PLC communications
- Home area networking, Electric Vehicle Charging and grid to utility meter communications etc.

The G3-PLC (ITU-T G.9903) was designed to provide a robust a robust OFDM based PHY for the hostile power line medium. The MAC layer is based on adaptation of the IEEE 802.15.4 MAC using 6LoWPAN (IPv6 over Low Power Wireless Personal Area Networks). A G3-PLC network is made up of one or more PANs (or domains), which is initialized and managed by a PAN coordinator. In addition to providing domain-wide management and control operations, the PAN coordinator also handles connectivity to other domains or the backhaul Wide Area Network (WAN) [10].Each registered node is identified by 16 bit ID short address and its domain ID. The 6LoWPAN adaptation layers defines bootstrapping protocol for devices to discover neighbors in a network. L2 routing based on LOADng routing algorithm, which is a robust technique that is capable or reporting a broken link, blacklisting of unicast neighbors and route cost calculation for efficient management of the routing table of each node. Mesh topology is used to supports hop-by-hop routing thereby ensuring self-healing capability;discovery of new link in case a link becomes unavailable. Only unslotted CSMA/CA for non-beacon supported PANs is used [11]. The Collison avoidance mechanism used is the Subsequent Segment Collision Avoidance (SSCA). A typical application of the G3-PLCis implementation of a PLC local area network (LAN) for use over the low voltage electrical network, to exchange commands and information between meters and concentrators for automated metering management (AMM) system[11].

The PRIME system was designed to support energy related services and is composed subnetworks defined with respect to transformer stations. A subnetwork is essentially a logical tree network made of up two types of nodes: the base (root) node and the service nodes. The base node acts as the master node and manages the subnetwork's resources and connections. Service nodes which are slave nodes follow a registration process described in Figure 2 to become part of the subnetwork. A service node is initially in the disconnected before it is registered as a terminal, where it is capable of communicating with other nodes in the network. In the Switch mode, a service node is capable of performing all the functions of a terminal as well as forwarding data from other nodes in a particular subnetwork.

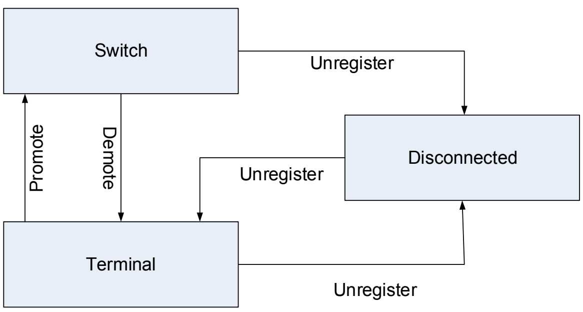

Fig. 2 Service Node States (source: [12])

Each node uses a 48-bit universal MAC address, called EUI-48 to uniquely identify itself during the registration process. The EUI-48 is also known as the subnetwork address (SNA). Each terminal node is assigned a 14-bit local node identifier (LNID) during the registration process and each switch node is assigned a unique 8-bit local switch identifier (LSID). The LNID and the LSID of the immediate switch to which a terminal is connected forms a 22-bit node identifier (NID), which is used to identify a single service node in a subnetwork. A device may have a number of simultaneous, connections each of which is identified by 9-bit local connection identifier (LCID)[12]. The PRIME network uses the CSMA/CA for access control to the transmission media.

The ITU-T G.hnem (ITU-T G.9902) standard specifies a standard that where the network is divided into a number of domains. Each domain consist of a domain master and a number of end-nodes. The domain master is responsible for a number of management functions such as[13]:

- Registration of new nodes into the domain
- Periodic communication of beacon to all nodes in the domain. Beacon frames information specific to domain operation such as domain name, domain ID, bandplan, spectral compatibility and security mode to be used.
- Gathering and maintenance of topology information from nodes of the domain
- Storage, processing and communication of statistics to the management centers.

Different domains of the same network may be managed by a global master (GM). Nodes of the same domain are identified by a node ID and can communicate to each other either directly or via relay nodes. Nodes of different domains in the same network can communicate using inter-domain bridges (IDB). Nodes of different networks can communicate over inter-network bridges (INB) which is a layer 3 bridging function. The G.9902 network can also communicate with alien networks via layer 3 bridges. The G.hnem network supports mesh topology which allows any network topology to be supported. A typical example of energy management application using the G.hnem network is illustrated in Fig. 3

In the tree-structured architectural model given in Fig. 3, the energy management HAN consist of utility-controlled and consumer-controlled appliances such as Programmable Smart Thermostats (PST) and Electric Vehicle Supply Equipment (EVSE) at the customer premises. Each HAN is a separate network, thus devices in each user premises connects to the utility access network (UAN) via the INB. The UAN could consist of a number of concentrator nodes for aggregating data from various HANs. The utility head-end unit acts as a global master of the UAN. Both Layer 2 and Layer 3 routing mechanisms are supported. The convergence layer is based on the use of 6LoWPAN to provide support for IPv6.In order to ensure the coexistence of the various narrowband PLC technologies, the use of preamble based mechanisms in addition to frequency separation and frequency notching were recommended in[14].

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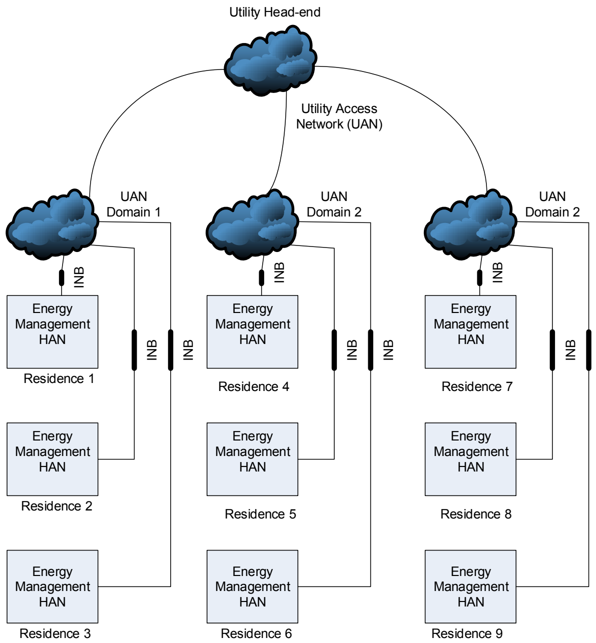


Fig.3 G.9902 Energy Management network Architecture

B. *Broadband PLC Access Networks: Architecture and Topology*

In addition to the use of broadband PLC technologies for in-home networking, these technologies can be used to provide utility smart grid and telecommunication services with higher data rate. The network architecture and topology for in-home networks are relatively simpler and smaller than that of access network. IEEE 1901 is based on two optional, disparate and non-interoperable physical layer technologies: the fast Fourier transform based FFT-OFDM PHY and the wavelet based W-OFDM PHY. An IEEE 1901 In-home network otherwise known as a Basic Service Set (BSS) consists of a BSS Manager (BM) and stations. Each stations can share information exclusively with other nodes of the same BSS. When a node is hidden from a BM, one of the stations can act as a proxy BM (PBM) as illustrated in Fig. 4.

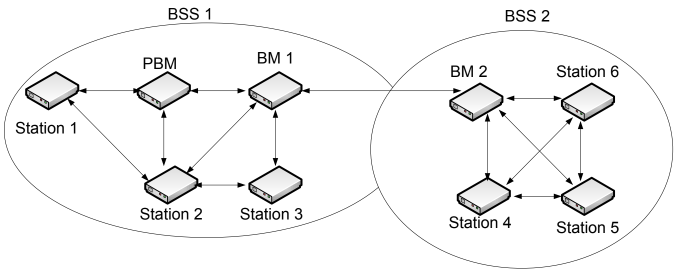


Fig.4 IEEE 1901 In-home network topology and components

A station can be chosen as the BM if it has the best connection to every station in the BSS or it has the best bandwidth management capability[15]. The BM can also be explicitly chosen by the user. All stations in a BSS share the same Network Membership Key (NMK), which is a 128-bit advanced encryption standard (AES) key that is provided for all the stations in a BSS. Each station in the BSS is assigned an 8-bit Terminal Equipment Identifier (TEI). The TEI is used for addressing in all frame control transmissions. Access to the power line transmission media is based on either CSMA/CA (CSMA/CA only mode) or a combination of CSMA/CA and Time Division Multiple Access (TDMA) for coordinated and uncoordinated modes. The topology and concept of the IEEE 1901 access network is significantly different from that of the In-home networks. The 1901 access network assumes a cell structure, which is built and managed by a cell manager [16]. An IEEE 1901 access network consists of the following types of stations:

- Head End (HE) station: this is the cell manager and connects the access network to the backbone or Wide Area Network (WAN) such as the internet.
- Repeater Stations (RP): these are stations that can repeat data from one station to another
- Network Termination Unit stations (NTU):provides gateway function between the access network and the customer premises equipment (CPE). The NTUs also bridges the access network to the customer in-home BPL network and other network technologies such as Ethernet, Wi-Fi and Coaxial cable networks.

The HE stations are assigned a short network identification (SNID), which uniquely identifies and logically separates the an access cell from its neighbors [16].Stations connect to a particular cell by association with the SNID of the HE of the cell. The HE allocates a 12-bit TEI to each station in the network. The combination of SNID and TEI is used for addressing to support functionalities such as routing, channel access, channel estimation and neighbor network detection. CSMA/CA is used as the default MAC protocol due to its suitability to the multi-hop and dynamic topology of the of the access network. However, a combination of TDMA and CSMA/CA is used to ensure deterministic media access for smart grid utility applications as well as to ensure deterministic quality of service for some real time applications such as video conferencing and Voice over Internet Protocol (VoIP).

The ITU-T G.hn is another standardized power line technology for broadband home networking over various types of wire media such as category 5 cable, coaxial cable and power line. In addition to use of OFDM in the physical layer, there are enhancements for supporting Multiple Input Multiple Output (MIMO) techniques as outlined in [17]. A G.hn network can have up to 16 domains each of which can include up to 250 nodes; one of which acts as the domain master (DM) [18]. Each endpoint node can support concurrent communication with at least 8 other nodes [19]. Fig. 5 illustrates the architecture of the G.hn network. The Global Master coordinates the resources and operations of the domains in a network. A nodes of the same domain can communicate with each other directly. Nodes of different domains communicate over the inter domain bridge (IDB). Connection to other in-home networks such as Wi-Fi, Zigbee and ITU-T G.hnem is realized over a network layer bridge. For smart grid applications, the ITU-T G.hn standard specifies a low complexity profile (LCP) that operates in the frequency range from 2 – 25 MHz. The ITU LCP is fully interoperable with the full ITU G.hn and is envisioned to reduce power consumption and component cost. Media Access Control is based on a MAC cycle which for the power line media is synchronized with the mains alternating current (AC) cycle (usually 2 AC cycles. The MAC cycle is synchronized with the AC cycle in order to mitigate the effect stochastic power line channel and noise. Each MAC cycle is divided into a number of time slots known as *transmission opportunities* (TxOPs), which is assigned to nodes in the domain for media access.

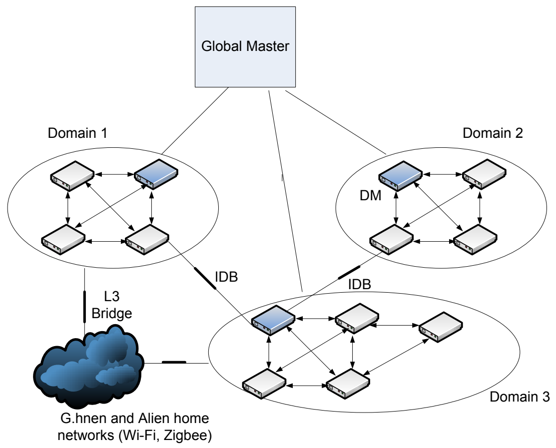


Fig.5 ITU T G.hn Network Architecture

III. GRID MANAGEMENT AND COMMUNICATION SERVICES

The electric power grid can be used to augment the telecommunication infrastructure deficit in developingcountries. This will significantly improve fixed broadband connectivity and last mile internet access. The statistics for the various telecommunication subscriptions for some African countries are outlined in Table 1. There are several applications of power line communications that ensures mutual benefits to both the telecommunication service provider and the utility company. These are applications are critical to ensuring the sustainable management of modern electric grids and accelerated mobile and telephony service access to developing economies.

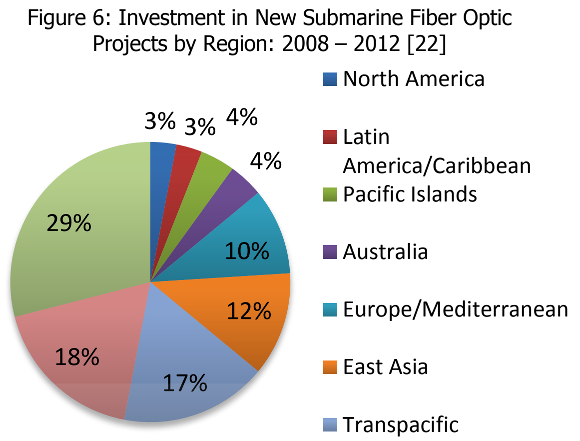
Table 1: Statistics of Telecommunication Subscription[20]

Parameter	Nigeria	Kenya	South Africa	Ethiopia
Fixed-telephone subscriptions per 100 inhabitants	0.2	0.5	9.2	0.8
Mobile-cellular subscriptions per 100 inhabitants	73.3	70.6	147.5	27.3
Fixed (wired)-broadband subscriptions per 100 inhabitants	0	0.1	3.1	0.3
Mobile-broadband subscriptions per 100 inhabitants	10.1	3	25.2	4.8
Households with a computer (%)	8.4	10.8	25.8	2.1
Households with Internet access at home (%)	7.8	14.2	39.4	2.3
Individuals using the Internet (%)	38	39	48.9	1.9

A. *Internet Access*

One of the major drivers of the economic development of any nation is the level of broadband Internet penetration attainable therein. According to research results released by the World Bank, a 10% increase in broadband internet penetration in developing countries guarantees a 1.3% corresponding growth in Gross Domestic Product (GDP) [21]. The broadband supply chain comprises of the international connectivity, a national backbone network and the last mile access network. All across Africa, the international connectivity aspect received a lot of attention around 2010 resulting in a lot of investments by various consortia (see Fig.6) [22].

From Fig.6, Africa is undoubtedly the region with the largest investment in new submarine fiber optic cables in the period under consideration. It is however quite unfortunate that the expected returns in investment in terms of an increase in broadband internet penetration is yet to be realized. In Nigeria for example, only about 10% of the total capacity of undersea cables in Nigeria is currently being utilized hence resulting in about 6% internet penetration due to a reliance on wireless access technologies. A key factor responsible for the low access to broadband internet in developing economies is the lack of adequate infrastructure for access by end users and customers. The access network derives its importance as a result of its proximity to the subscriber and comprises of the wired and wireless access technologies. The fixed broadband subscription for various regions illustrated in Fig. 7 shows that Africa has the lowest subscription.



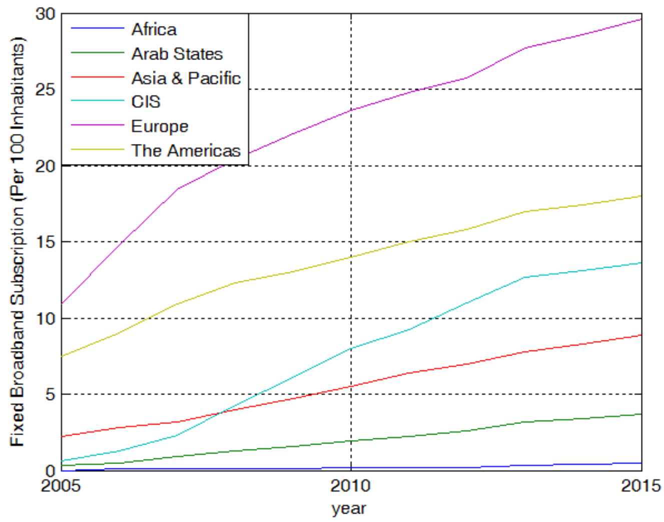


Fig. 7 Fixed Broadband Subscription for Different Region (source:[23])

The goal of achieving greater broadband penetration in developing nations can only be achieved by leveraging on a combination of various access technologies.The Broadband over Power Line (BPL) technology involves the transmission of information over conductors used for electric power transmission. International Organizations like the Organization for Economic Cooperation and Deployment (OECD) support the use of this technology due to its apparent ease of deployment and negligible environmental impact. The fact that previous rural electrification projects have been run before makes it possible to use such infrastructure to boost the last mile internet access.An

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internet Service Provider (ISP) can rent the electric network of a power utility company to provide internet access to all customers that are connected to the electric power grid. This makes it possible to provide broadband internet connection to any point *where there is a power cable*. The sustainability of utility company is enhances as it ends up making money from the use of its network instead of renting for telecommunications service. A case study of this mutually beneficial synergy is in the agreement between Canal+ (an Internet Service Provider) and Beninese Electric Power Company (SBEE). In January 2016, Canal+ in Benin Republic entered an agreement with Beninese Electric Power Company (SBEE) to provide internet access services over the utility operator's network. The utility company will receive fees for the use of its infrastructure while leveraging the internet access for smart grid applications such as geo-referencing of its electricity poles and managing electricity consumers [24]. The PLC internet access platform can also be used to realize Advanced Metering Infrastructure (AMI). AMI is capable of providing consumer directed smart grid initiatives such as [18]:

- Two-way communication system
- Connects millions of nodes and reaches every consumer
- Highly secure communication systems for delivery of meter data to utility
- Service management such as disconnect and reconnect of customers and monitoring of meters for tampering.

B. *Electricity Theft Prevention*

Electricity theft is a major challenge to the sustainable and profitable operation of electricity utilities in developing countries, especially in remote areas[25]. Electricity theft takes many forms: from compromising or intimidating utility company workers to by-passing and tampering electricity meters. There are several engineered ways of tampering both electromechanical meters and smart meters. Tempering in electromechanical meter may involve taking connections directly from distribution lines, Grounding the neutral wire, Putting a magnet on electromechanical meter like neodymium, Inserting some disc to stop rotating of the coil, Hitting the meter to damage the rotating coil or Interchanging input output connections. But these tampering strategies can be drastically minimized by using smart meters with capability for real-time monitoring and anti-tampering circuitry[26]. Advanced Metering Infrastructure (AMI) has been used in developing countries to control electricity theft because it provides a new sensor based approach which are installed in the electrical equipment. Smart meters have the ability to record zero reading and it can alert the utility system by sending data through the PLC infrastructure.

C. *Distribution Automation and Electric Vehicle Management*

Electric Vehicles have often been suggested as a helpful solution to reduce fuel consumption and air pollutant emissions where concerns about its security, availability and its negative impact on the environmental are worrisome [27]. Electric vehicles play a crucial role in decarbonizing road transport and at the same time need careful management. EV charging is one of the fundamental schemes in the electric vehicles' applications. EVs can offer benefits due to their flexibility in charging and discharging time span and introduce a useful concept called "Vehicle-to-Grid" (V2G) capability. Smart-grid technology can facilitate EV-charging (grid-to-vehicle, or G2V) load during off-peak periods [28]. This can be useful in reducing electricity system costs by providing a cost-effective means of providing regulation and monitoring services, recyclingreserves and reducing capacity. EV can act as a controllable load as well as a distributed storage device. When connected to the electricity network, the battery of an EV can supply power during peak load times and thus increase the reliability and availability of the grid. Different approaches have been proposed in literatures for integrating Large EV fleet into electric grid is in two folds, that is, the electric vehicle owner and utility entity. In [29], a distribution automation architecture which explicitly involves an EV aggregator was proposed. The aggregator coordinates all the required operational activities like communicating with the distribution system operator (DISTCOs), transmission system operator (TRANSCOs) and energy service providers. It maintains the link between energy market players and the electric vehicle owners.

D. *E-Learning*

Globally, there is a growing concern about the shortfall in the number of qualified teachers in the various institutions of learning. This trend is more prevalent in the developing and less developed nations than the advanced nations. In 2013, United Nations Educational and Scientific and Cultural Organization (UNESCO) estimated that by the year 2015, about 1.6 million more teachers would be needed globally to achieve the goal of Universal Primary Education [30], [31]. There is however an associated cost to this as countries that require additional teachers need to increase their overall budget for teacher's salaries. Sub-Saharan Africa has the greatest need for extra teachers and Nigeria alone accounts for two-fifth of the gap. For example, reports have shown that $4 billion is needed annually in Sub-Saharan Africa to pay the additional salaries of the additional primary school teachers required by 2020[32].

Just as the Information and Communication Technology has been used to solve many other challenges in government and financial institutions, it can also be leveraged upon to complement the efforts of the available qualified education personnel. At the level of higher institutions, Information technology in teaching and learning has created a reliable platform to change how university students learn by using more efficient,modern and cost effective alternative tools such as electronic learning (E-learning). E-learning is a learning method and a technique for the presentation of academic curricula and content through the internet or any other electronic communication media such as multimedia, compact discs, satellites, or other new education technologies[33], [34]. The Open and Distant Learning is a model of e-learning that can be used to drive sustainable development in the rural areas. This model of learning which has been in place before now has not achieved the desired aim due to challenges such as poor funding, poor power supply, poverty, poor ICT penetration and low tele-density. The use of Power Line Communication technologies will go a long way to address a number of the challenges already highlighted.

IV. CONCLUSION

Sustainability of an electric power system depends to a large extent on the ability of the operator to cost effectively manage the network as well as minimize both technical and non-technical losses. Moreover as indicated by statistic of mobile broadband subscription for various countries and regions, there is a deficit of telecommunication infrastructure in developing economies. Standardized narrowband and broadband can be used address this challenges. Modern narrowband technologies can be used to provideenergy-related services such as smart metering, automation distribution, Electric Vehicles Charging, demand-side response etc. Broadband PLC technologies can also be used to provide energy-related services while simultaneously functioning as telecommunication access networks for providing broadband internet and voice services to remote/underdeveloped areas. Broadband technologies can also be used for implementing local area networks (LANs) and community networking. The use of PLC for telecommunication services is an 'infrastructural plus' that is capable of accelerating into human and economic development. The flexibility, low cost and support for high data rate features of broadband PLC opens up the opportunity for sustainable provision of diverse information and communications (ICT) services for accelerated development of underdeveloped areas. For example, a system of distance learning for primary and secondary school can be provided in rural areas where availability and quality of teachers is a serious challenge. Tertiary Institutions can also set up satellite campuses where video conferencing and video on demand services are used to provide cost effective educational services. Other ICT services include e-government, community networking, telemedicine and e-health.

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