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Assessment of Communication Metrics for Smart Grid in Developing Countries

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ABSTRACT:*Standard smart grid (SG) systems deals with the defined and predictable variables that are outcomes of stable systems. In the case of developing countries, the smart grid deals with qualities that are sometimes subject to tertiary system behavior that are either more difficult to predict or are a result of transient properties which are majorly unpredictable. In this paper, detailed assessment of SG domestication and its communication metrics is presented. Through a simulation study, the two most critical metrics are quantified quantitatively for use in proposed gamma SG properties that determine the power supply profile of the grid system. A smart grid therefore would prove more ideal for this.*

KEYWORDS:*Artificial machine interface, Cloud broker, Demand side management, Smart grid, Smart load time domain management,*

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I. INTRODUCTION

In today's world, smart devices like smart phones, smart domestic appliances, smart factories, etc, abounds. These smart paradigms can be structured and with and intention to aid our day-to-day activities. This trend is fostering efficiency and autonomous operation and control which have more far reaching effects on daily and long term lives of humans. Communication metrics such as latency and throughputs are the most vital for sustainable grid provisioning. This is because; intelligence is added to the grid network [1] for automation and orchestration using hybrid cloud ecosystems (HCE) [2]. Recently, the use of (HCE) has seriously improved allocation, resource provisioning, and management of multi-tenanted distributed energy resources [3-6]. The implication is seen in the overall resilient architecture with very minimal errors controlling complex smart grid environments.

Most developing Nations are yet to explore networked based intelligence to the existing power grid [7]. This has largely contributed to zero cognitive grid systems that possess a lack of automated self-monitoring and self-healing. In these countries, there exists monolithic energy value chain with a resultant effect of elongated outage, electricity theft and low equipment optimization [1]. By definition, a smart grid is a complex electrical power model that houses variety of distributed energy resources, end-user smart metering, integrated controls and other efficient energy management resources [8].

Smart grids are utilized in other parts of the world to effectively transform today's centralized system into a more interactive units that adapt dynamically to the demand and supply parameters obtainable on a real-time basis [9]. This makes grids to be up and running while operating in a sustainable while running without interruption [10]. Designing the Smart Grid system requires enabling consumers to have options for their choice of supply. This will ultimately reduce the overall environmental impact of the electricity supply system, maintain or foster high levels of system reliability, quality and security [11]. Clearly, reliability, efficiency, and safety improvements of power distribution networks maybe realized via communication and smart grid components. This will ultimately enhance the energy efficiency to the benefits of end-users.

The issue of communication metrics assessment has not been fully investigated. Efficiency in smart systems results once resources are optimized. Since most electricity networks comprises a number of communication protocols that define their versatility, standardized information exchange and categorization of communication domain relative to all data exchange systems is critical. As a result, smart grids need to be supported by a highly heterogeneous data network with high standards due to the uniqueness and delicacy of the command protocols [12], [13], and [14]. In the case of Nigeria, the electricity grid is currently plagued by maintenance problems and other inherent inefficiencies [15]. In order to benefit from smart grid, network improvement needs to be reinforced in the communication.

In this paper, an assessment of communication metrics for smart grids in developing countries will be reviewed. Also, a holistic smart grid architectural landscape that clearly separates the power and communication domains to enable "evolving smart grid" engineers provide efficient networking solutions is presented. A case study investigation into communication metrics for a smart grid system is highlighted.

II. REVIEW OF LITERATURE

A. Smart Grid Assessment

There have been several studies on Nigerian power system designs without any visible improvement. For instance, the authors in [16] had carried out reliability investigation on the 330 kV high voltage transmission networks of the Nigerian Electric Power Authority (NEPA) now Transmission Company of Nigeria and observed the inherent deficiencies of installed generating capacity needed to meet the increasing load demand. The study in [17] looked at the effect of low power factor on the utility grid in the Nigerian market. The authors [18] developed a framework for improving voltage profiles thereby avoiding grid collapse. The work in [19] explored power system analysis using Shiroro complex in Nigeria. The work looked at various loading and generation conditions, modeling, power flows and fault level while showing the need to for additional power generation facility and voltage compensation at receiving ends. The authors from their findings proposed regionalization in transmission and analyzed one of the regions in Nigeria as a case study. The work in [20] investigated the techno-economic and environmental merits of the inclusion of wind power to diesel power system for electricity generation in Nigeria using the hybrid optimization model for electric renewable (HOMER) software. A representative sample of literatures in Nigerian grid assessment has been studied in [21]-[29]. Clearly, Nigeria has not made progress in the areas of smart grid systems.

Most recent works have carried out comprehensive assessment of smart grid systems just to evaluate the suitability of different communication technologies needed to enable different smart grid applications [30]. In most African countries like Nigeria, Botswana, Zimbabwe, Namibia and Zambia, smart grid initiative is absent expert in South Africa [31]. In fact, South Africa is about the only African country that has experience in Smart Grids [31]. Similarly, various other studies on feasible smart grid architecture in developing countries have been studied in [32-36].

B. Nigerian Energy Industry Context Assessment

For the most populous country in Africa, Nigeria is expected to lead as the energy giant of the sub-region in terms of smart grid energy initiatives. Looking at the estimated population density and its expected economic growth by 2030, it becomes critical to review the major drivers of the economic growth using its energy consumption trajectory [37]. Accessibility remains a huge challenge despite the non-utilization and weak distribution model [38], [39]. Smart grid communication systems will be very useful in Nigeria considering that the power generation capacity from existing plants in Nigeria stands at 6538MW since 2005 [37]. Clearly, the huge centralized electricity production in Nigeria is largely from natural gas (39.80%), hydro (35.6%), crude oil (24.80%) and coal (0.40%) [37], [40], [46]. By December 2013, the total installed or maximum capacity of the power plants was 6,953 MW while available capacity was 4,598 MW with actual average generation being 3,800 MW [37]. In December 2014, the total installed capacity of the power plants was 7,445 MW while available capacity was 4,949 MW with actual average generation less than 3,900 MW [41], [42]. Assessment report shows the major drop in generation was due to unavailability of natural gas caused by vandalized gas pipelines as most of the power plants depend on natural gas [37]. However, the total energy consumption in Nigeria is relatively low. This is because as 2009, the consumption in Nigeria was about 4.6 EJ or 11MTOE. About 60% of the population depends on fuel wood, charcoal and biomass; the distribution stands at biomass (80%), crude oil (13%), natural gas (6%) and hydropower (1%) in 2011[43], [44].

Despite the Electric Power Sector Reform (EPSR) act of 2005 which dissolved and deregulated the electricity industry, Nigerian government invested between $3-$16 billion to help revitalize the sector, yet there were little or no results [45]. Though the involvement of independent power plants (IPPs) via state-owned NIPP, have encouraged private participation to satisfy the growing energy demand, smart grid option appears to be the best solution. This is because the Nigerian population is geometrically increasing; the industrialization is gradually growing thereby making electricity intensive technologies very imperative.

A summary of the projected explorations of the renewable energy deposits in Nigeria is provided in Table 1. Notably, the renewable power energy potential in Nigeria is enormous. Solar power potential in Nigeria is about 427,000 MW, which is estimated at 3.5-7.0 kWh/ m2. Nigeria also has a wind potential energy of 150000 terra joule per year, biomass at 144 million ton per year, LHP of 10,000 MW and SHP of 734 MW [22][23].

Comparing this abundant renewable energy potential with the current power generation in Nigeria, which is about 5000 MW, tapping into the resource will not only be sufficient for meeting the demands of the growing population but will also, be available for economic trade to neighbouring countries.

Table 1: Nigerian Renewable Energy (MW) Profile [37], [46]

Feasible Grid Resource	YEAR			
	2014	**2015**	**2020**	**2030**
Hydro (LHP)	1938	4000	9000	11250
Hydro (SHP)	60.18	100	760	3500
Solar PV	15.0	300	4000	30005
Solar Thermal	-	300	4000	30005
Biomass	-	5	30	100
Wind	10.0	23	40	50
All renewable	2025.18	4628	15966	63032
All Energy Resources	8700	47490	88698	315158
% of Renewable	23%	10%	18%	20%
% RE Les LHP	0.4%	1.3%	8%	16%

C. Towards Smart Grid Communication Systems

The Smart Grid communication evolution has been predicted to effectively transform a somewhat centralized system into a more interactive unit [12]. This is because it can adapt dynamically according to the demand and supply parameters obtainable on a real-time basis. This quality makes the grid to be up and running while operating in a sustainable manner with optimal resources. The numerous benefits of a SG to include [46]-[49]: improved facilitate the operation and monitoring of generators of all sizes and technologies, ability for consumers to participate in optimizing the operation of the system. Designing SG system in such a way as to enable consumers have options for their choice of supply, will ultimately reduce the overall environmental impact of the electricity supply system, maintain or foster high levels of system reliability, quality and security. With critical consideration on power loading in Smart Grid deployment using Smart Grid with supports for communications, real time data monitoring, control and optimization will be beneficial.

D. Smart Grid Management System

For effective load distribution, it is obvious that most African countries are facing similar energy-related challenges, including those related to energy supply, reliability, and climate change matters, hence; there is need for an efficient energy management model. These countries can employ smart grid energy management (SGEM). This is the proactive, organized and systematic coordination several factors including procurement, conversion, distribution and use of energy to meet the requirements, taking into account environmental and economic objectives. It also includes planning and operation of energy-related production and consumption units. It is the forward-looking, organized and systematic coordination of the procurement, conversion distribution, and utilization of energy in order to cover requirements and which takes ecological and economic objectives into consideration [47]. This covers not only the organizational and information structures required for implementing the energy management system, but also the technical resources needed for its realization. For a robust communication metric, SGEM must leverage Internet connectivity where the web clients through the field buses make appropriate connections. Here, the user control panel links the billing meter and load sensors through the gateway to the Internet. Internet connectivity is critical for real time data exchange and can be deployed via a number of channels such as LAN, WLAN, and VLAN, etc [47]. The intent of the connectivity which must be bidirectional is intended to accommodate real-time feedback as well. In accessing the Smart grid communication systems in the developing world, a summary of differences between a robust smart grid system and the legacy grid model in Nigeria is depicted in Table 2.

Table 2: Comparison Ideal Grid System and Nigeria Grid [47]

Grid Characteristics	Developed Grid	Nigerian Grid
Customer participation	Customers are informed about grid changes beforehand.	Customers are rarely informed about outages or other changes in advance.
Accommodates Storage	Clusters of storage are found.	No storage
Response to system disturbances	Responses and protection systems provide sufficient isolation to trip conditions.	Traces of protection but are grossly inadequate.
Resilience against attack and disaster	Existence of system awareness and reaction mechanisms to perceived threats	Inadequate sensory perception to identify and perceive threats or attacks to the network
Enables new products/Services and Markets	Significant wholesale markets that is poised to growth.	Great potential for markets with the right frameworks in place
Information flow	Bidirectional	Unidirectional
Troubleshooting	Remote/system	Manual
Auto-recovery	Present	Absent
Remote Control Ability	Present	Absent

E. Available Communication Channels for a Smart Grid

With reference to provision of network connectivity in Nigeria despite being touted as the largest telecommunication market in the world, it is clear that there are numerous challenges with communication systems in the developing countries including Nigeria [50]. Communication network infrastructure deficiency could limit the available communication potential in the in Nigeria. Other issues include: network coverage associated with infrastructural challenges, network coverage, overall quality of service and adequate regulation.

III. MATERIALS AND METHODS

In this Section, a novel SG model is presented in Fig. 1. In order to modulate the quantities of energy generated through a suitable communicating channel, a gamma SG generation module is introduced to aggregate the energy generated in a suitable format capable of being transmitted via the selected communication channel. For aggregating vertically integrated utilities, for power plants, and co-generators, the Gamma distribution is utilized to illustrate the smart grid continuous probability density function of random power plant variables. The data can be accessed through independent market operator or Nigeria energy regulatory commission (ISO NERC) servers. This has a two way linkages as depicted in Fig. 1. In context, the operations/performance of DISCOs is monitored by NERC through the Cloud servers.

A. Smart Grid Cloud Integration Architecture

The execution of demand side management (DSM) as part of the communication infrastructure via load management procedures in SG was built on a layered time-delay optimization architecture, shown in Fig. 1. This was constructed with the communication network capacity as a constraint. The minimum average time delays and QoS for the SG switching optimization goal are satisfied by a neural network inter-layer capacity constraint. The established SG architecture whose power generation (DER) was modeled using probability theory. In this case, the exponential distribution is the probability distribution used to characterize the time between events of generation. Aggregate generation capacity is modeled continuously and independently at a constant average rate. This gives the particular case of the gamma distribution. Hence, each generation plant gives an exponential continuous analogue of the geometric distribution with a memory less property. In this design, the load demand is compensated with the ahead-supplier availability which the neural network monitors for possible grid compensation vis-à-vis the power pools. The dynamic load scheduling or energy balance is done by the automated smart grid.

The Independent System Operator (ISO) receives energy bids by pool participants and establishes activity with respect to the participants. This is done by monitoring minimum pricing model that satisfactorily meets the load demand in the power pool. The competition among the pool participants was realized as non-cooperative exponential and gamma distribution. The power bids by the GENCOs, as well as the load demand provides a spot electricity market in which the ISOs sets the GENCO dispatches to compensate for the power pool generation and load demand. The essence of the SG initiative is to maximize all participants' advantages notwithstanding the GENCOs power pool intended benefits. The ISO broker uses an established spot-price to clear the pool market. In the economic model, the transaction payment considering each participant is harmonized based on the spot price and the available power transaction.

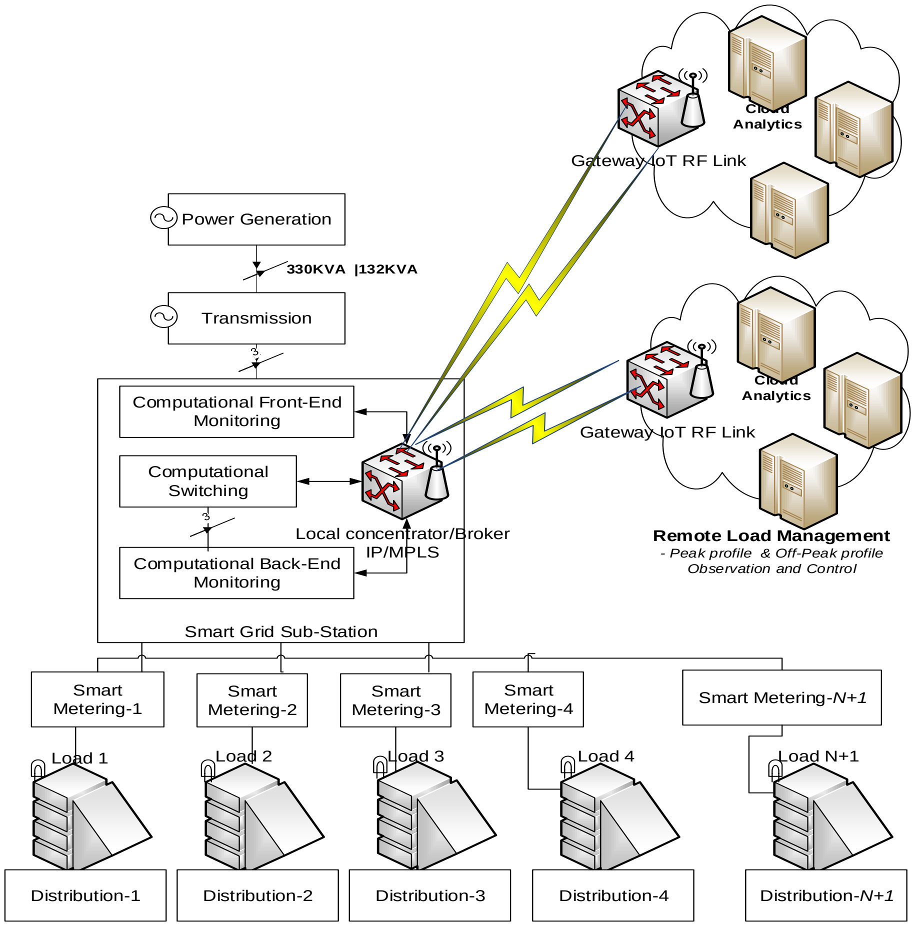

Fig.1. Proposed layered smart grid gamma architecture

B. Smart Grid Cloud Layered Integration:

The gamma architecture in Fig. 1 uses two-layer data center model where various optimization SG schemes discussed in [51] were employed. The schemes include: SG Stackelberg Game Algorithm, SG CHAOS-Flower Pollination Algorithm (CFPA), SG Cuckoo Search Algorithm (CSA), SG Differential Search Algorithm (DSA), SG Cournot Algorithm (CA), and Game Theoretical Schemes. The SG Cloud architecture and the underlying interoperability functionalities strongly rely on neural network application algorithm which is used to determine the system performance accuracy. Hence, Internet Protocol/Multiprotocol Label Switching (IP/MPLS) was considered in the SG Cloud setup for achieving the communication metrics in Figure 1. At the Cloud layer, IP/MPLS communication was introduced to provide end-to-end integration for SG utility transmission and sub-station network of Fig. 1.

C. Smart Grid Gamma Algorithm

Algorithm I facilitates convergence, multi-layer virtualization and resiliency using IP and Ethernet for edge to Cloud transactions. While the Ethernet provides cost-effective high bandwidth physical interfaces, the IP is used as a link between the smart grid services from the edge to the active supervisorycontrol and data acquisition (SCADA Cloud).

Algorithm I: AMI local concentrator/ local aggregator
Define (AMI local concentrator)
Input: local ID, destination ID, queue size, link Information
Output: Gather up streams and dispatch the infinite queues to Global sink
DrawAMI_local Connection ( ); AMI_Global Connection *j* ( )
Initialize: *i*, iterations T, $\vartheta^k \leftarrow 0$; $\vartheta^k(\text{CIU} \ \& \ AMI)$
Map AMI data (individual nodes)
While all data (i) not converged (Buffer) do
For all i (AMI) $\in \{0, \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots n-1\}$ **do** read (i);
For i:=0 to N-1 **do** read (φ[i]);

For i:=0 to N-1 **do** read (∂[i]);
For i:=0 to N-1 **do** read (n_{k+1}[i]);
For j:=0 to N-1 **do** read ϑr[i]: = φ([i]);+ ∂([i]);+………(n_{k+1}[i]);
For i:=0 to N-1 **do** write (j[i]);
$\vartheta^{k+1}(\text{CIU \& AMI}) = \frac{1}{N}\sum_{i=1}^{N} \vartheta^{k}$
End
End
End
End
End
End

IV. RESULTS AND DISCUSSION

A simulation of some data using load time domain (LTDOM) information for the Nigerian power grid reveals that time delays in implementation of commands can significantly influence the performance of the grid relative to blackouts. During load scheduling on the SG network. Riverbed Modeler Academy Software was used to setup the experimental design for LTDOM architecture depicted in Fig. 1. The idea in this paper is to analyse the most critical communication metrics of SG system for a developing country such as Nigeria. This work will now compare six distinct scheduling algorithms for SG communication metrics including: Neural Network LTDOM Algorithm (Proposed NNLA), Stackelberg Game Algorithm (SGA), CHAOS-Flower Pollination Algorithm (CFPA), Cuckoo Search Algorithm (CSA), Differential Search Algorithm (DSA) and Cournot Algorithm (CA). SG Metrics such as Service delays, throughput payload. These were investigated in order to understudy the impact of load scheduling on SG ecosystems. Table 3 shows the tuning parameters for the communication metrics design. In the distribution automation, CISCO 7705 SAR-HC and 7705 SAR-W were used in the field area network to provide connectivity to sensors and field devices (such as reclosers, voltage controllers, and capacitors) for remote control and monitoring, as well as aggregation for SG AMI. It depicts SGLTDOM dispatching mode with energy users. It included an extended neural network LTDOM (NNLA) for SG utility, which uses IP/MPLS communication network and offers trust from a circuit-based network to an IP network while enabling network convergence, virtualization and resiliency.

Table 3: Simulation Design Parameters for LTDOM

Design Parameters/Specifications	Descriptions
Smart grid link Connection	40GB Ethernet
Grid Servers	7705 SAR-18
Cloud Virtualization Type	EXSi Scale
Local concentrator	7750 SR
Load balancer Address	Auto Configured
Server farm gateway	Fog layer (Cyber_ethernet4_slip8_gateway_adv);
Number of Clients	50 AMI nodes
IP Core	IP/MPLS Enabled OpenFlow
Profile Configuration	Http
Client Address	DHCP Assigned
Attack Vector	DDoS (450 GB)
Transmission substation	2

Fig. 2 shows the SG LTDOM media access delay on Ethernet switching interfaces in Fig. 1. It denotes the timeframe between two or more consecutive allocation of resources to similar users during load management on the grid. During load scheduling on the SG network, it was observed from the riverbed statistics engine that the SSGA, Proposed NNLA, SCFPA, SCSA, SDSA and SCA had 32.25%, 15.32%, 28.22%, 25.40%, 20.16% and 4.03% respectively. This implies that as load demands in the peak periods is been shifted to the off-peak periods, the proposed NNLA utilized optimum resources on the grid network when compared to other schemes. This will make the objective of reducing the utility bills and peak loads feasible in an SG gamma design.

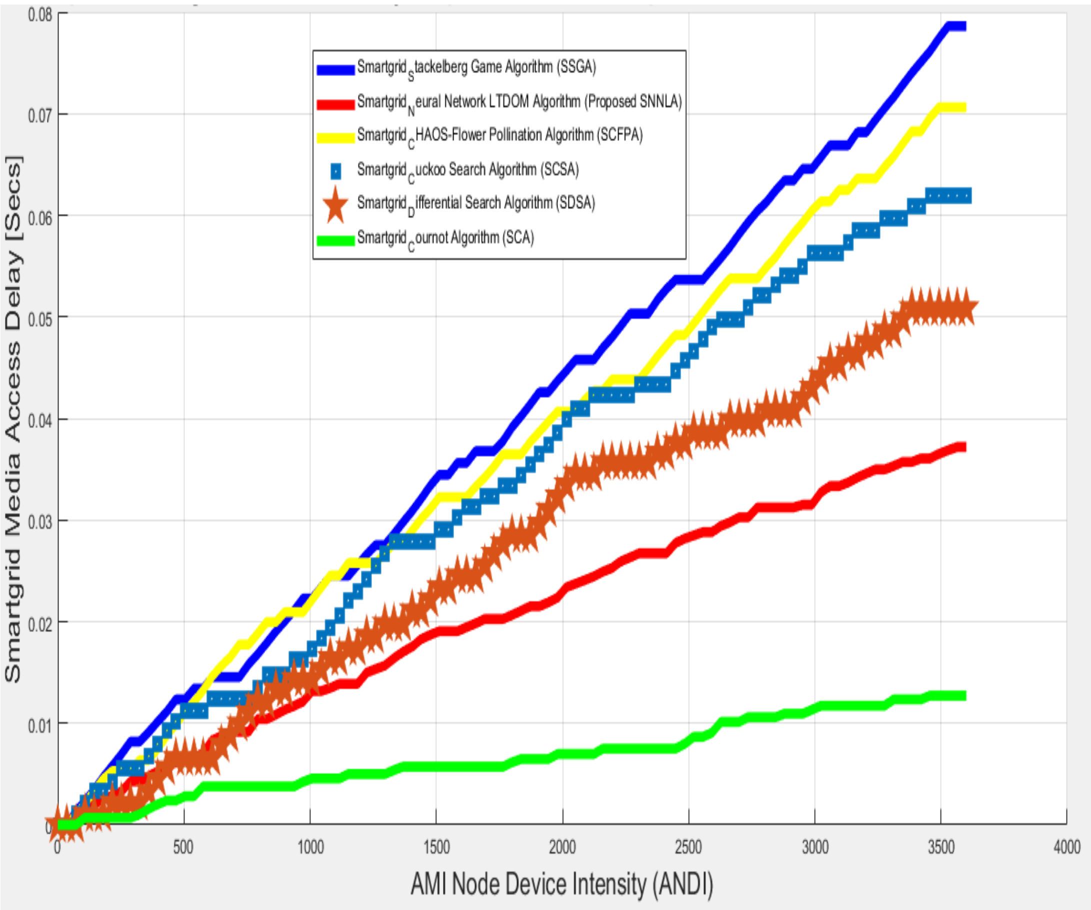

Fig.2. SG LTDOM media access delays

Fig. 3 shows the SG LTDOM service throughput as another important communication metric. Looking at the gamma structure of the SG network, service throughput describes the aggregate sum rate of successful load management data traffic delivery over the entire network link logically. Despite SG LTDOM service constraints such as physical medium, attacks, processing power, traffic protocols, the maximum achievable throughput is always preferred. During load scheduling on the SG network, it was observed from the riverbed statistics engine that the SSGA, Proposed NNLA, SCFPA, SCSA, SDSA and SCA had 21.68%, 24.09%, 16.86%, 15.66%, 12.04% and 9.63% respectively. This implies that as load demands in the peak periods is been shifted to the off-peak periods, the proposed NNLA utilized optimum resources while delivering satisfactorily on the grid network when compared to other schemes. This will make the objective of reducing the utility bills while optimizing peak load demands.

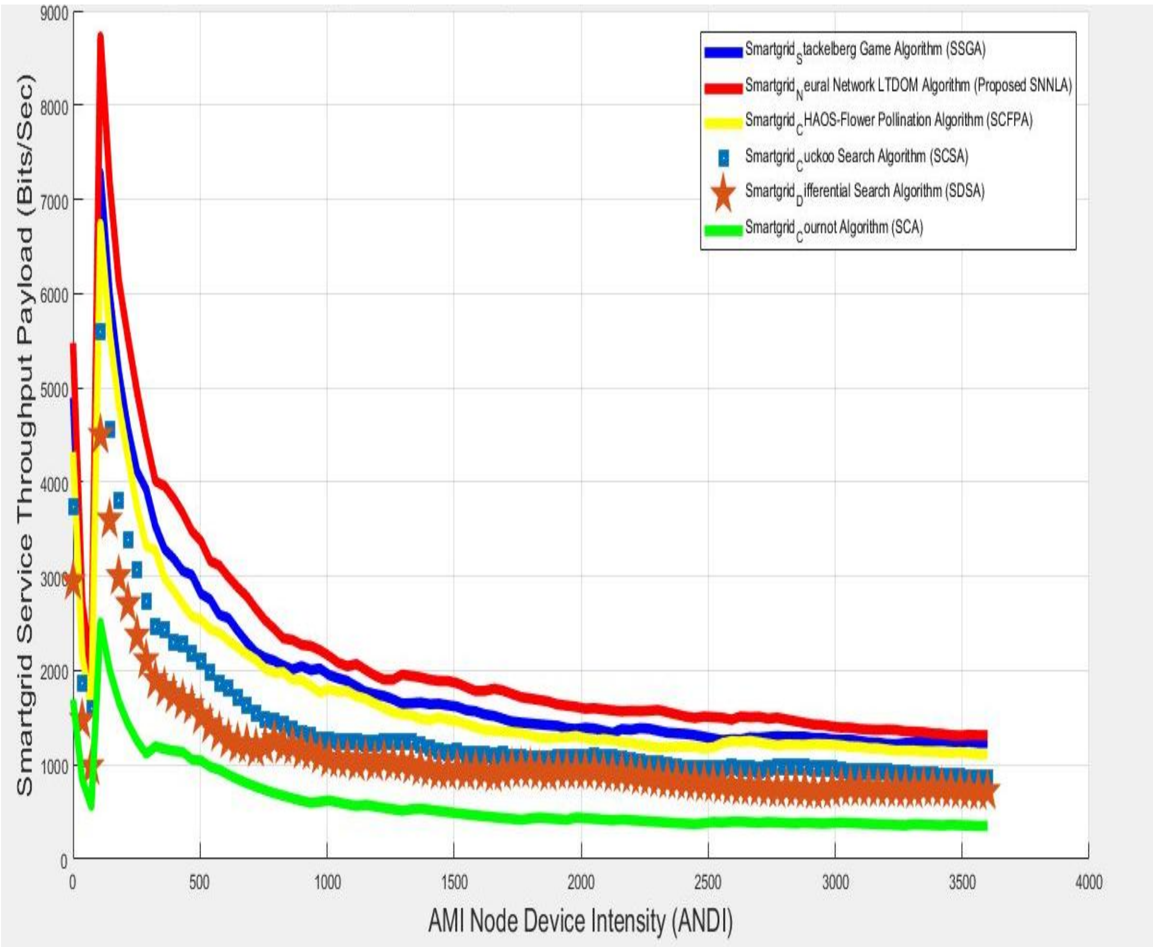

Fig. 3. SG LTDOM service throughputs

V. CONCLUSION

A review of the communication potential in the Nigerian electricity network reveals that there is a huge potential for the improvement of smart monitoring and control of grid parameters. As can be seen from the plots of the responses of the selected SG parameters, the values are suitable for good monitoring. In the SG network validation, six schemes were used for validation on simulated Smart grid layered architecture. In all instances of load shifting for demand side management strategy, the with selected network algorithm were used to simulate minimize the peak load demand. SGSGA, SGCFPA, SGCSA, SGDSA and SGCA where compared with the proposed scheduling scheme. SG metrics such as service delays, throughput payload, energy data received, cryptographic overhead, and service traffic availability were selected and investigated in order to understudy the impact of load scheduling on smart grid ecosystems. The results show that the proposed SG algorithm offered significant improvements compared to a generic radial grid. Table 4 shows summarized results from LTDOM metrics.

Table 4: Result summary of SG LTDOM validation metrics

Validation Metrics	Proposed SNNLA	SSGA	SCFPA	SCSA	SDSA	SCA
SG LTDOM Service delays	12.28%	18.78%	18.64%	14.0%	18.49%	11.56%
SG LTDOM Media access delays	15.32%	32.25%	28.22%	25.40%	20.16%	4.03%
SG LTDOM Service throughput	24.09	21.68	16.86	15.66%	12.04%	9.63%

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