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Comparative Study of Smart Grid Communication Technologies

Afroz Ahmad[1] and Saleha Ahmad[2]

[1,2]Computer Science & Engineering Department, University of Engineering and Technology (UET), Lahore, Pakistan

***Abstract*— A large amount of electricity is consumed by datacenters to operate and bring massive electricity bills to operators. A new kind of electrical grid, called the smart grid, is emerging nowadays. The main function of smart grids is to enable two-way communications between the power generators and consumers. Smart grid technology brings several salient features to facilitate the efficient and reliable transmission of power. Revolutionary change in the smart grids is due to the facilities and moderations by ICT. New and advance smart grids are due to the upgraded communication standards. Many emerging technologies offered by telecommunication sector have been introduced. WAN, FAN and HAN networks are introduced in wire communication. Similarly, ZigBee, Bluetooth, WiMAX and other cellular networks are in wireless categories that are introduced in the smart grid networks. Recently the usage of more mainstream and reliable communication network, Fiber Optics has been adopted by Smart grids. In future Smart Grids will be more intelligent and smooth as Power Line Communication (PLC), Optical Ground Wire based Fiber Optics (OPGW) will be the highly active and fast communication networks within the Smart Grids. It focuses on the data rates, advantages, disadvantages and standards off different communication techniques.**

***Index Terms*— Smart Grids, Communication Technologies, Data Centers, Wireless Technologies and Wired Technologies**

I. INTRODUCTION

SMART grids can be referred as succeeding generation power grids. Outdated grids are generally used for the propagation of electricity from the high-power generators to the long distant customers. Despite of these traditional power grids, smart grids have two-way energy and data flow that makes them automated and more smart power delivery networks. Many advance and distinct features are introduced in the smart grids. In our research datacenter power management features of smart grid are:

A) Enhanced reliability

Advance technologies are introduced in the smart grids that results in better self-restoring and self-monitoring without involving manual control. Smart grids can minimize the power failure with less disruptions due to the real time monitoring devices. Automatic problem detection, immediate power line error response, and sorting of error links are its main features. Datacenter service accessibility can be improved by consistent and quality power supply.

B) Active rating

Higher power demands of any region can be detected and informed to the electricity consumers by the smart communication and detection technologies. Electricity rating is so active in smart grids that in high demand periods its price goes up and similarly in low demand periods electricity price goes down. To motivate consumers to cut their load, the electricity price increases during high demand periods and decreases during low demand periods. Therefore, electricity consumers consume lesser in high demand span that's proved as an economic gain by using this energy in low peak period.

C) Higher sustainability

Smart grid is an integrator of distributed power generation and renewable energy. Many bidirectional flows of power and disseminated feed-in points are allowed in smart grid technology. Frequencies and variations of renewable energy can be managed by smart grids consistent power flow is also maintained by smart grids by their advance monitoring systems. So, any electricity consumer can have power more easily from the grids and can also be a power supplier by installing power generators.

D) Demand response

Generators consumers' interaction in real life can be made with demand response and adjustment of demands can be made accordingly. Emergency load lessening signals and accordingly respond to these signals are the capabilities of smart grids advance tools. Elimination of added reserve capacity cost now lessen or reduced by these capabilities [1].

E) Data Centers

Collection of IT equipment's, servers, storage devices and network devices are accommodated in a specific space known as data centers. Lightning, power and cooling systems acts as a site infrastructure, from which IT equipment is supported.

Data center description includes collecting and evaluating technical and functioning information. Centers functions,

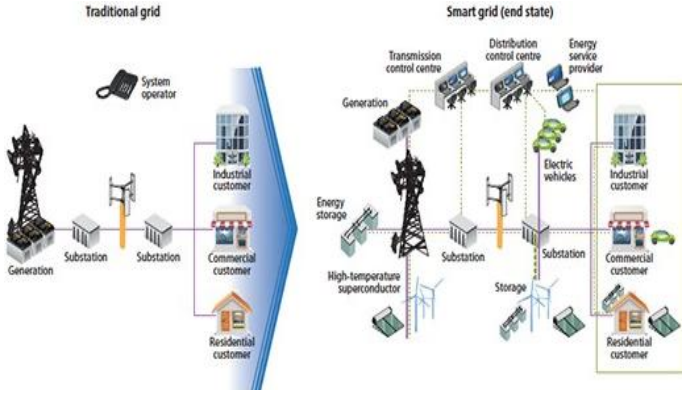

Fig. 1. Comparison between Traditional and Smart Grid

enabling technologies, load profile, and computational task characterization are the four key attributes of the computational task.

i). Data center is basically any type of service that a data center offers. Just like storage and web servers, data bases and intense computing are the commonly offered services by the data Centers now a day.

ii). Enabling Technologies are the services that provide the data and information to the data centers specific to data centers to help in DR package participation. Real time maintenance and management of IT equipment, cooling and measuring of temperature and humidity conditions for air management are provided by these technologies.

iii). End node loads characterization according to its functions is referred by Load Profile. Three categories of end use load are discussed according to the environment: i) IT equipment, ii) cooling or site infrastructure, and iii) support loads, all these three categories consist of UPS and lightning.

iv). Computational task characterization includes characterizing the tasks performed by the data Center servers to provide a great understanding about the type of the services that has been provided by the data centers. During a DR event this process allows potential jobs to travel to another located data centers. Some of these tasks need local resources and may have different analyzing requirements than those existing in another data Center (co-location). In this type of situation computational tasks cannot be drifted. Although these computational tasks can be run on a chance after or before DR event [2].

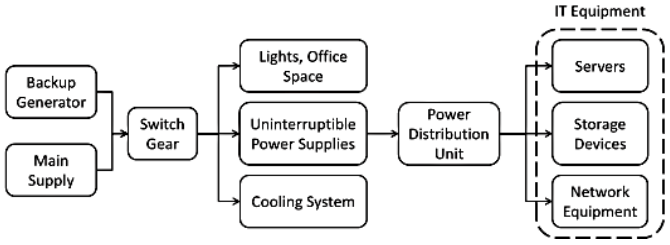

Fig. 2. Data Center Overview

F) Data Center and Grid Integration

After the integration of Data Centers and Smart grids, this integrated network is now self-aware to manage local requirements and become grid-aware that informs about any change in grids and its additional gains these results due to the power demand and price management system. Integration of data centers and grids can be done through programming, advanced enabling techniques and automated software that records and analyze the real time power pricing information from markets. To detect the zones of grid integration data center must consider recognizing that how it fits within analogous data centers [2].

In this paper, the comparative study of various wireless communication standards will be compared in detail. The paper is organized as follows: Section II gives the summary of the related work done in this field. Section III presents details of the wireless technologies available for Smart Grid communication. Section IV discusses communication challenges in Smart Grid and comparative study of various communication techniques used in Smart Grid. Section V concludes the paper by summarizing the overall study.

II. RELATED WORK

In this section, we will focus on some of the work done in smart grid communication technologies. In [3] author focused on some of the basic wireless communication technologies e.g., WiMaX, Zig Bee, Bluetooth, Wi-Fi etc. In another related work [4] author presented the communication techniques used in smart grids. A brief paper that has some main technologies with their advantages and disadvantages. That paper shows the comparison between the tradition old grids and the new grids as well. Research paper [5] focuses on the infra structure on smart grids and the recent smart grids communication technologies, research challenges and future needs are also discussed by the author.

III. COMMUNICATION TECHNOLOGIES IN SMART GRIDS

The two-way communication has been introduced in the smart grid. This two-way communication improved the real time price and billing systems those results in more satisfied consumers. Data centers having grid operators can get all the accurate information about the energy consumption of any user and manage this information further in the peak hours. Real-time data flow is essential for smart grids superlative operations [4]. That perfection can be obtained by wired, wireless and some other fast communication networks and technologies. There are many advantages of wired, wireless and other infrastructure, including cost, simplicity, range and sources many emerging technologies offered by telecommunication sector has been introduced. WAN, FAN and HAN networks are introduced in wire communication. Similarly, ZigBee, Bluetooth, WiMAX and other cellular networks are in wireless categories that are introduced in the smart grid networks. Recently the usage of more mainstream and reliable communication network, Fiber Optics has been adopted by Smart grids. In future Smart Grids will be more

intelligent and smooth as Power Line Communication (PLC), Free Space Optics (FSP), Optical Ground Wire based Fiber Optics (OPGW) and Quantum Communication (QC) will be the highly active and fast communication networks within the Smart Grids Low cost and reliable connection for far away and long distant areas wireless techniques are more preferred as compared to wired.

A) Wired Communication Technologies

Digital Subscriber Line (DSL): DSL stands for digital subscriber lines. DSL permits data to transfer within the telephone lines. Without out any additional cost of deployment DSL has been used in smart grids. Many other alternatives of DSL like ADSL (Asymmetric DSL) supports up to 8 Mbps for downstream and 640 Kbps for upstream, ADSL 2+ with up to 24 Mbps and 1 Mbps for downstream and upstream respectively. And VDSL (for Very high bit DSL) providing up to 52 Mbps for downstream and 16 Mbps for upstream but only for short distances.

Power Line Communication (PLC): In PLC's power line cables have some modulated carrier on them for the establishment of two-way communication. PLC is further divided into two types.1) Narrow Band PLC. 2) Broad Band PLC. It is the cost-effective communication mean of smart grids. PLC allows the power infrastructure utilization to exchange the monitoring and data flow messages. In HAN environment PLC is not -until now- a suitable solution, because of the lack of interoperability and standards, the multi-protocol and the multi-vendor environment in HAN networks [8]. PLC technologies are preferred by utility operators because their reliability advantage compared with other communication techniques.

Fiber Communication: Fiber optics is the main communication network that has been used in the connection of substations for the operation and control purposes and that's all due to its large advantages including the robustness to noise and electromagnetic interferences and its capacity to transmit in the large distances with the high bandwidth According to our analysis optical communication is the major part in the transmission and distributions in smart grids. According to recent studies Optical Power Ground Wire (OPGW) usage will be more convenient in the transmission and distribution lines as the blend of the optical communication and ground make possible the long-distance propagations and higher data rates [6].

B) Wireless Communication Technologies

Long Term Evolution (LTE): Long Term Evaluation (LTE) or 4G standard is now a day a trending wireless standard having proficiencies ease of handover in different networks and bandwidth. LTE is suitable for NAN networks such that QoS, 75 Mb/s peak load rate and up to 300 Mb/s of downloading rate [7].

IEEE 802.16 (WiMAX): WiMAX or IEEE 802.16 is a long distance supported technology having 10 km Broad band and 100Mbps of data rate. WiMAX was basically introduced to manage thousands of users over the long distances' 802.16j is the latest version of WiMAX that support the multi hop techniques with fluent handover that makes it more flexible and comfortable to use resulting in higher coverage that makes it a perfect choice for NAN and AMI [8].There is another version of WiMAX , 802.16m that is in development stage. That will provide the higher mobility 350km/h and 100Mbps data rate.

ZigBee: ZigBee is based on IEEE 802.15.4 standard and a communication technology specifically for physical and medium access layer. Low-rate wireless personal area networks (LR-WPANs) is another name of ZigBee. Two types of devices are introduced in a ZigBee network: 1) Full Function Device (FFD), 2) Reduced Function Device (RFD). Network management, routing and establishment is done by FFD and RFD supports the functionalities of FFD. Three nodes are present in the network: coordinator, router and end device [9]. Empowerment of multi-vector interpretability and creation of application profiles are the strong features of ZigBee. This profile contains the description of different axioms like application compatible devices, message type and data formats etc.

IEEE 802.11 (Wi-Fi): Many communication technologies are collected in one 802.11 standard that is known as WIFI for WLAN networks. That is a remarkable and diverse structure due to its CSMA/CA and its unlicensed frequency bands 2,4 GHz and 5 GHz [6]. IEEE 802.11n is the recent version of Wi-Fi that has the highest data rates up to 150 Mbps. Another version is IEEE 802.11a/g having data rate of 54 Mbps. IEEE 802.11e is another standard important for SG applications because of it Quality of Service. 802.11s [10] standard over physical layer allows multi-hop and mesh networks [10]and at the last one 802.11p standard for wireless networks for V2G systems [11].

Bluetooth: IEEE802.15.1 standard is short range wireless communication technology that can be configured as Wireless Two connection topologies are defined in the Bluetooth: piconet and scattered. The connection that has been made between two blue- tooth enable devices i.e., between two smart phones, is known as "piconet", while scatter net is the collection of interconnected piconets [13]. Due to all these distinct features Bluetooth is implemented in smart grid applications (Table II).

Cellular Network Communication: From the past years the excessive growth has been seen in the cellular communication networks. Cellular techniques are in the process of improvement and these improvements are in data rate (Table I), coverage area and moving forward towards 4G and 5G. That is the improved version of GSM. Base of cellular communication was formed after the 1G by Wireless Local Area Network (WLAN) that provides the fluent communication to the users with higher data rates. Multiple users can access the service and it is done by the spread spectrum techniques.

Table I: Data Rates Comparison of Wireless Standards

Standard	Wi-Fi	Bluetooth	ZigBee	ZigBee
IEEE Standard	802.11b/g	802.15.1	802.15.4	802.15.4
Nominal Range	10 – 100	1 to 10	10 - 100	10 – 100
Range (m)	100	10	40	90
Chip set	CX5311	Blue Core 2	XB24-B	XBee-Pro

Table II: Smart Grid Communication Technologies [14]

Technology	Standard/Protocol	Max. Data Rate
DSL	ADSL	1–8 Mbps
	HDSL	2 Mbps
	VDSL	15–100 Mbps
Power Line Communication	Home Plug	14–200 Mbps
	Narrowband	10–500 kbps
Fiber Communication	PON	155 Mbps–2.5 Gbps
	WDM	40 Gbps
	SONET/SDH	10 Gbps
WiMAX	802.16	75 Mbps
Wireless mesh	Various (e.g., RF mesh, 802.11, 802.15, 802.16)	Depending on selected protocols

IV. COMMUNICATION CHALLENGES FOR SMART GRIDS

Major challenges for smart grid communication are performance, efficiency and interoperability. Real time monitoring is an important feature of smart grids and for this reason consumers and suppliers must relate to full dynamic and sufficient network and that can be done with smart data centers and more advance technologies. Coordination with in the equipment's and control devices is a key component of smart grid infrastructure that's why the integration of networking and communication techniques with security and power system is needed (Table III). High scalability and quality of service is needed between the wired and wireless networks, as Smart Grids must face millions of high potential consumers. Due to the increasing complexity of SG communication, privacy and security will also delay electrical grid upgrading. As, there is the requirement of some unique and advanced techniques against illegal access and cyber vulnerabilities.

V. CONCLUSION

Smart Grid is the new technology which requires suitable wireless or wired technologies to be implemented. The selection of communication technologies depends on different parameters like range, reliable architecture, limitation of power consumption) viz. network span, data rates, security and reliability, number of channels, available bandwidth etc. The details of different wired technologies like Power Line Communication (PLC), Optical Ground Wire based Fiber Optics (OPGW) and wireless technologies like ZigBee, Bluetooth, WiMAX are discussed in this paper. The comparative analysis of all wired and wireless technologies illustrates are important parameters including advantages and disadvantages of that technology. The details mentioned in this comparative study will enable the users to choose the suitable technology that can be used as per the application spectrum in smart grid. The routing protocols in communication networks for smart grid used in home appliances and smart meters, AMI networks and operator control center these factors can be studied for further future research. This will require the study of different class of protocol families for every network type in all smart grid segments.

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Table III: Comparison between Communication Technologies for Smart Grid

Communication Technology	Function	Coverage	Advantages	Disadvantages	Applications
DSL	DSL stands for digital subscriber lines. It permits data to transfer within the telephone lines.	Between 300m to 7km	Installed for residential users Infrastructure is established	Expensive Not appropriate for long distances	AMI FAN
PLC	PLC stands for power line communication A technology that permits to send data over existing power cables.	Narrow Band-PLC: 150 km Broad Band-PLC: 1.5 km	Infrastructure for SG is already installed. Cheap Basically, separated from other networks.	High signal attenuation Difficulties in high bit rates Channel distortion Routing Complexities Interference with electric appliances and electromagnetic sources	Narrow Band-PLC: AMI, FAN, WAN Broad Band-PLC: HAM,AMI
Fiber Communication	A technique for transmission of information from one place to another through optical fiber.	Between 10km to 60km	Robustness against Ultra-high bandwidth Interference Very Long-distance	Expensive Not suitable for metering applications Upgrading is difficult	WAN, AMI
4G LTE	LTE stands for Long Term Evaluation A standard for high speed wireless communication, mobile devices and data terminals	0-5km up to 100km	Same as 3G More flexible Enhanced technology	Expensive Latency	V2G, HAN, AMI
WiMAX	It is basically data communications technology providing high speed data over a wide area. It is based around the IEE 802.16 standard	Between 10km to 100km	Longer distances comparing with Wi-Fi Appropriate for high range of simultaneous Sophisticated QoS Connection-oriented	Expensive Complex Network management Licensed spectrum use	AMI FAN WAN
Zigbee	ZigBee is based on IEEE 802.15.4 standard. A communication technology specifically for physical and medium access layer.	Up to 100m	New ZigBee SEP 2.0 standards with full interoperability with IPv6 based networks	Low bandwidth Not suitable for large networks	V2G HAN AMI
Wi-Fi	IEEE 802.11 standard is known as WIFI for WLAN network	Between 300 m outdoors and up to 1 Km	Cheap Has several use cases Network deployments and equipment's Flexibility	High interference Simple QoS support High Power consumption	V2G, HAN, AMI
Bluetooth	IEEE802.15.1 standard can be configured as Wireless Personal Area Network (WPAN). A wireless technology for transmission of data over short distances.	Up to 100m	Cheap Suitable for tiny devices with low resources Low power consumption	Bandwidth is low Not appropriate for large networks	HAN BAN IAN