A Survey on Information and Communications Technology Infrastructure for Smart Grids

Daisy Nkele Molokomme, Chabalala S. Chabalala, *Member*, *IEEE* and Pitshou Bokoro, *Member*, *IEEE*
Department of Electrical & Electronics Engineering
University of Johannesburg, Johannesburg, South Africa
e-mail: {201132400@student.uj.ac.za, schabalala@gmail.com, pitshoub@uj.ac.za}

***Abstract*—Smart Grids (SGs) aim to improve the aging power system grid into a modernized grid with the utilization of the advanced communication technologies in the industry. The incorporation of communications technology in power systems enables two-way flow of electricity and information within the grid system. SGs emerge as the next generation technology in power systems, as a result of the increasing demand of upgrading the conventional grid into the more modernized grid, with the aim of resolving some of the major crisis such as the environmental and energy crisis posed by the existing grid. In order, to deploy this intelligent grid, a sustainable, energy efficient, flexible, scalable, and secure communication infrastructure need to be designed and implemented to address these issues. There are several surveys and studies on the Information and communication technologies (ICT) architectures to develop a suitable protocol of applying the proposed advanced and up-to-date communication and networking technologies into the power system, to enable the intelligence features of the grid system. This paper reviews the works on communications technologies on SGs, with the objective of addressing the issues related to ICT infrastructure, and the recent communication technologies with their corresponding communication requirements.**

Keywords: 5G; cognitive radio (CR); information and communication technologies (ICT); smart grid (SG).

I. INTRODUCTION

The increase in fuel prices, energy crisis, greenhouse gases emission, the increase in penetration of the renewable energy resources, and the increasing demand of energy are some of the major issues behind the driving force of upgrading the traditional grid into the intelligent grid. The basic power system topology has remained the same for the past decades,[1] with its operation limited within these domains, generation, transmission, distribution and customer domain with the solid ICT infrastructure. The conventional grid cannot resolve the major issues mentioned above due to its characteristic features i.e., one-way flow of information and electricity, its requirement of manual monitoring and restoration, limited control and also provide few choices to customers. Smart Grid is an intelligent power network that combines various technologies in power, communication and control which can monitor and optimize the operations of all functional units from electricity generation to end-users (customers/consumers) [2]. The emerging of SG presents some key benefits including, two-way flow of information and electricity, distributed generation, self-monitoring and self-healing, pervasive control and intelligent sensors through the entire network. The utilization of two-way flow of information and electricity, allow the SG to create an automated and distributed advanced energy delivery network [3] whereas the introduction of distributed generation and pervasive control enable the efficient delivery and exchange of real-time data between the devices within the domains [4]. Hence, the design and implementation of an efficient, sustainable, flexible, complex and secure communication infrastructure is of great importance, for high penetration integration of distributed renewable energy (DER) resources i.e. photovoltaic (PV), wind systems, e.tc in the SG [5].

Recently, several studies and surveys has been conducted and some are still underway on the ICT architectures with the objective of designing and implementing the suitable infrastructure which meets the communication requirements and standards of the SG [1], [3],[5],[6]. The SG system can be categorized into three domains, SG HAN (Home Area Network), SG NAN (Neighborhood Area Network) and SG WAN (Wide Area Network) where each domain has unique communication requirements and protocols based on the operation of SG. SG HAN is the in-door topology network, which interconnects all the smart meters utilized in the end-user's premises. It is capable of covering areas up to $200m^2$ with a data rate ranges from 10 to 100kB/s [7], so this implies that SG HAN is only applicable for small-scale smart grid application. SG NAN is deployed within the distribution domain of SG, to enable the distribution domain with regards to monitoring and controlling electricity delivery to each household interconnected to the network, considering the amount of energy available from the supply and the energy demand from the customers [2] and it is also considered as the heart of the SG communication network, since it is responsible for transporting the massive amount of data from the intelligent devices utilized on the network. This type of SG element can also be applicable for large-scale SG applications.

In [2],[8], authors conducted surveys on SG NAN and SG NAN based on cellular communication technologies respectively, with the aim of addressing critical issues in the implementation of SG NAN, which includes, network topology, gateway deployment, routing algorithm, related standards of NAN and security. SG WAN serves as the backbone of the communication links between NAN's and the utility control centers. These categories of the SG mentioned above only differ from each other by the amount of area it can be able to cover as well as the rate at which it can be able to transmit the data on the network, So, this paper, will provide a brief overview on the advanced communication technologies proposed by other researchers, with the aim of selecting the most relevant communication technology from the others, which has the capabilities of meeting the demanding communication requirements of SG, i.e. Quality-of-Service (QoS), latency, scalability, security, etc. In [9], the software defined radio [10] communication technology, cognitive radio has been presented as the promising technology to resolve the issue of inefficient amount of spectrum in SG, and also enhance some of the communication requirements of SG, such as scalability and reliability. Although the CR and 5G seems to be the promising technologies in the deployment of SG, other communication technologies also need to be surveyed to make a fair and reasonable conclusion on the appropriate communication technology for SG applications. The contribution of this paper is to provide a comprehensive survey on the works based on this field including their pro's and con's, issues related to the recent proposed communication technologies and also present a solution in the form of an architecture or framework which can be appropriate for the information flow between the smart meters and control centre to enable proper decision making and processing of data.

The rest of this paper is organized as follows. Section II: Related works on this field are briefly discussed. Section III: Brief discussion based on recent communication technologies along with their pro's and con's and issues related to them. Section IV: Communication requirements of SG are discussed based on the cognitive radio and 5G communication technologies. Finally, we conclude this paper on Section V.

II. RELATED WORKS

Communication network is considered as the key element of the successful SG, several surveys and studies on the ICT architectures are still underway, with the hope of developing the suitable communication infrastructure, since the current technologies cannot meet the communications requirements demands of the SG [1]. Authors in [5], presented an empirical study of communication infrastructures towards the smart grid, with the objective of answering the fundamental question at the end of the study on how to design, and practically integrate the communication infrastructure with power system. Gabor, et.al in [3], presented the design aspects of network assisted device-to-device (D2D) communications, with design challenges outlined, including peer and service discovery while Lei, et.al in [11], [12], designed the energy efficient communication networks for DR in Smart Grid, with the objective of developing an algorithm to overlook the performance of the communication network in terms of the demand response and the packet losses on the network while in [13] the relaying technologies were presented. The Future renewable electric energy delivery and management (FREEDM) system was utilized as the test bed of the case study, with the predominant protocol of Distribution network protocol 3.0 over Transmission control protocol/internet protocol (DNP 3.0 over TCP/IP) adopted to measure the real time data delivery performance. But the TCP/IP does not meet the communication requirements of the SG. Xi et.al, in [3], surveyed the works based on the enabling 4technologies for the smart grid, with the focus solely placed on the three major systems of the SG, smart infrastructure system, smart management system and the smart protection system. It is reported that the macro and micro grid paradigms, take advantage of other SG technologies and are widely regarded as the critical components of the successful SG [3].

An overview on both the wireless and wired communication technologies was presented, considering the fact that, two types of information paths should be separately designed for accommodating the SG characteristic feature of two-way flow of information and electricity. In most cases wireless communication technologies (ZigBee, Cellular communication (LTE, ALTE, 5G, etc.), Wireless mesh network, Satellite Communications, etc.) present more advantages over wired communication technologies (Powerline communications (PLC), Fiber optic, etc.). In [2], it is reported that wireless communication technologies may be the only practical solution for smart grid covering the last mile communications [6] in the distribution domain. Though wireless communication technologies pose more advantages over wired communication technologies, such as low-cost infrastructure, since the existing wireless communication infrastructure can still be utilized for the SG applications, and ease of connection to unreachable areas [1]. But then, the attenuation of data signals due to the transmission path is a major concern in the wireless communication technologies. Several issues have evolved with the improvisation of the conventional grid into smart grid, which caught the attention of both the scholars and researchers in the field, including the design and implementation of the suitable ICT infrastructure for SG, particularly the infrastructure which enables the information flow between the smart devices and data centre.

III. COMMUNICATION TECHNOLOGIES

Reported in [3], the system of the functional smart grid infrastructure consists of energy, information and communications infrastructure underlying the smart grid. But then, the ICT's infrastructure of the aging grid system is solid with outdated communication technologies, and a lack of communication abilities. Hence the design and implementation of the intelli-grid is compulsory, since it presents the benefits to SG, such as the enhanced sensing and advanced communication and computing abilities [1]. Two types of communication infrastructures to enable the flow of information need to be implemented for the successful operation of SG, i.e. From sensors and electrical appliances in the end-user's premises to smart meters and the other path, from the smart meters to the data centers, as illustrated in the proposed SG architectures [1], [2], [5],[14]-[16]. For the first flow of information, recent papers proposed some of the popular communication technologies i.e. wired and wireless communication technologies such as powerline communication (PLC), Zigbee, wireless mesh, digital subscriber lines (DSL), e.tc. But then since there are many communication technologies proposed, this paper will only give a brief review on promising technologies for SG applications; PLC is a wired communication technology/technique which utilizes the existing power lines in distribution and transmission domain, to transmit a data signal at a speed range of 2-3Mb/s. The role of the PLC on the intelligent grid is still an open issue, since it was only applicable for remote metering and control in the utility industries. PLC technology presents itself as a promising technology due to its advantages such as, low installation cost will be required due to the fact that the existing infrastructure can be utilized to provide service for SG applications, and its also well suited for the SG urban area applications, such as smart metering and control of data. But then this technology is not able to meet some of the communication requirements of the SG, since it has a low bandwidth, so it cannot be able to accommodate any application which requires a bandwidth above 20Kb/s. ZigBee is a wireless technology which is designed for radio-frequency applications that require low data rate, long battery life, and secure networking [3] and is also based on IEEE 802.15.4 standard [13] along with ZigBee smart energy profile (SEP). ZigBee is considered as the good option for some of the SG applications such as advanced metering infrastructure (AMI), and home area network (HAN), due to its advantageous features on these applications. For the second flow of information, which is from the smart meters to utility's data centre, cellular technologies were the presented as the promising technology to meet this demand [8]. Cellular communication technologies, i.e. Long-Term Evolution (LTE), Advanced Long-Term Evolution (LTE-A), 3G, 4G, 5G, e.tc have been presented as the most promising and relevant communication technologies which meets the demanding communication requirements of the SG.

In most instances, the cellular communication technologies provide more advantages over other proposed communication technologies, including the fact that the existing cellular mobile communication infrastructure will be utilized for SG deployment which results in low installation and maintenance costs for utilities, the smart devices embedded on the power grid such as smart meters, a massive amount of data will be generated, therefore a reliable and fast operating infrastructure will be required to gather and transfer that data at small interval for processing (AMI) and decision making at data center. Therefore, cellular communication technologies provide sufficient bandwidth for such applications, since a certain technology will be used to integrate the devices with the existing power grid, this result in SG being vulnerable to cyber-attack. Therefore cellular technologies presents promising applications for these issues in SG deployment.1G is the initial generation mobile technology, which basically uses the analog as the transmission scheme, then 2G evolves to upgrade the 1G applications and provide more positive features than that of 1G, it consist of a data rate of 200kb/s, with the transmission schemes of TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access) , it is also capable of providing the GPRS services to the operators, then 2G has been improvised to 3G which have a bandwidth of 5MHz, under the transmission scheme of WCDMA (Wideband Code Division Multiple Access), LTE is regarded as the 4G, due to its advanced LTE features. LTE is a cutting edge technology which includes some extraordinary features that were never used before in wireless and mobile communications [17]. LTE presents more advantages over other cellular technologies mentioned before, due to its flexibility, quickness and also has more capacity, but it also has the negative impact on the communication network of SG including, sharing of the communication infrastructure, since a vital information on the SG will require a complex security strategy to avoid any cyber- attack which may occur. But 4G cannot meet the demanding requirements of SG in terms of throughput, latency, and number of connections since it was not designed for the applications of SG. Then the evolution of 5G seems like a promising technology for the implementation of SG communication structure.

5G is defined as the revolutionizing mobile communications providing pervasive and ultra-broadband fiber-like experience for everyone and everything to consume emerging mobile services, such as three dimensional or ultra-high-definition video sharing, machine type communication (MTC), intelligent transportation systems (ITS), and smart homes among others [18]. 5G technology is also considered as the vision of the next mobile generation technology, with promising characteristic features such as high data rate, extremely low latency, etc. Although 5G presents itself as a promising technology it has a challenge to support the fast response, since the large-scale SG applications requires extremely quick communication technology to respond to any event occurring on the communication network. Compared with 3G and 4G, 5G has more advantages than other cellular communication technologies, with regard to latency, the latency of 4G is below 50ms which is half of 3G technology, so this shows that both of these technology cannot meet the latency requirement of SG, since SG latency is below 100ms while 5G is capable of achieving a latency of 1ms.

The other critical issue faced by the SG, is the lack of the ability in the current communication technologies to support the two-way communication due to their low amount of coverage and bandwidth, between the end users and the suppliers, whereas the wireless communication technologies deployed in the communication infrastructure between the smart meters and the control centre support the two-way flow of information, so these infrastructures will be prone to interference from other users interconnected on the network and also the lack of expanding the bandwidth due to the less amount of channels available will also be an issue. So, this calls for cognitive radio (CR) based communication technology, which presents some key features to resolve these issues by taking advantage of the spectrum crisis.

IV. NEXT GENERATION SMART GRIDS

This section briefly outlines the communication requirements of the SG, based on the most recent and popular communication technologies, cognitive radio (CR) and 5G which presents the promising characteristic features of enhancing/improving the demanding communication requirements of SG. The usage of CR and 5G in SG applications, will not only improve the communication requirements of SG, but it will also enable the SG to be open to any future technologies while utilizing the current technologies in the industry.

A. Quality- of- Service (QoS)

With the evolution of SG, a demand of being applicable to the large-scale SG, is increasing, therefore smart devices employed on the infrastructure will require a good coverage for the delivery of the good quality of the real-time information on the entire network.

B. Security and privacy

The improvisation of the conventional grid into the SG, will introduce the deployment of the smart devices on the network along with the bi-directional flow of information on the network. These devices will be vulnerable to cyber-attack due to the vast amount of real-time data generated from them in a short period of time and delivered to the control centers for processing and decision making. Therefore, a robust, secure and complex communication infrastructure is of good importance to resolve the issue of the security on the network. So, the introduction of CR in SG applications will reduce the interference which the communication might be prone to, by increasing the insufficient amount of spectrum on the network. Security should also be implemented on the end user's side, since information gathered from the smart meters for billing and decision-making purpose will be very critical/sensitive to be exposed to any intruders.

C. Bandwidth

Each SG applications has their own bandwidth requirements which ranges from low, medium, to high radio frequency range. For the small-scale SG applications, the low to medium radio frequency should be sufficient enough for data delivery on the network, whereas on the large-scale applications, medium to high radio frequency is enough to meet the requirements. So, the application of SG on the large-scale area, will require a secure communication network with large bandwidth for the delivery and transferring of the real-time data gathered from the smart devices employed, so the employment of CR based on the IEEE 802.22 [19] standard which has the ability to transfer a vast amount of data gathered from the device at a fast rate to the control centre, seem to a promising solution to the above mentioned issue. Also, the communication network should be robust enough to provide the required bandwidth to reduce both the transmission and distribution losses encountered on the network. To provide a secure, reliable and efficient delivery of the SG applications to consumers such as video sharing, utilities have been more dependent on the wireless communication technologies to solve this issue, but then this has resulted in an increasing demand of the bandwidth which these technologies cannot meet since they were not designed for these type of services.

D. System Reliability

System reliability has always been one of the priorities, in the design of SG and operation due to the costs outages occurring from the end users side. So, billions of the smart devices will be interconnected on the system, which will require constant monitoring and controlling, so a reliable network is required to be able to accommodate those devices along with their requirements.

E. Latency

Latency is defined as the time between when the state occurred and when it was acted upon by an application [20]. In some of the most critical applications in SG such as advanced metering infrastructure (AMI), demand response (DR), etc. the delay of the information transmission between the devices will not be tolerated.

V. COGNITIVE RADIO AND 5G NETWORKS FOR SMART GRIDS

In this work, we propose a CR and 5G based communication network as shown in Fig. 1. Since most of the works reviewed in this field, has proposed the communication networks which were separately based on each of the above-mentioned technologies [19],[21]-[23] , which results in some of the communication requirements of the SG not met. The concept of CR technology presents itself as the core technology to resolve the issue of the increasing demand of radio spectrum, by enabling the frequency bands to opportunistically utilize the primary user's (PU's) which are

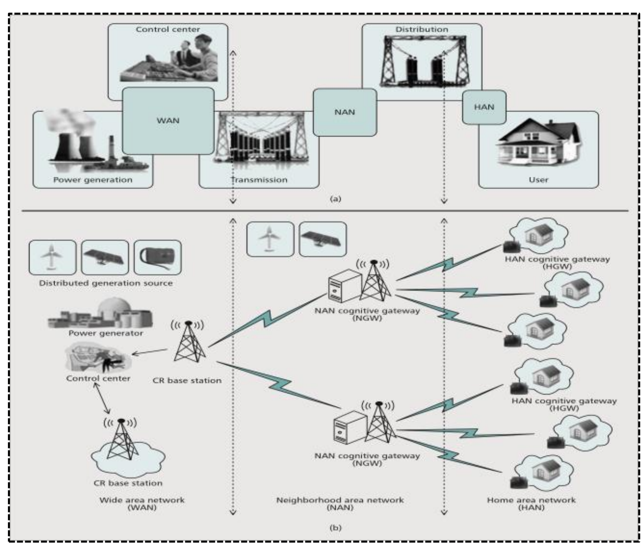

Fig. 1. CR based communications architecture for Smart Grid [24].

not densely occupied [21] and enhance other communication requirements of SG. In this context, PU's is defined as the television station transmitter [19], In Fig. 1, comparison between the traditional grid and smart grid architectures has been presented. The conventional grid paradigm has been presented along with the sub-domains (HAN, NAN, WAN) of the SG architecture, these sub-domains can be distinguished by their coverage service area and the rate of data.

The HAN enables the information flow between the smart devices utilized in the consumer's household such as, smart meters (SM), thermostats, washing machine, etc. for proper management of the energy efficiency and demand response on the network, it is also capable of covering the area ranges from 1 to 100m at a data rate of approximately tens of kb/s. NAN covers the area between 100m to 10km, and also allow the real time data from the smart devices on the network to flow at a speed of approximately hundreds of kb/s, it is used to collect and gather the information regarding the energy consumption from the smart devices in the consumer's household and transfer it to the utility's data centre through WAN (covered area ranges from 10 to 100km at a data rate of several Mb/s) for proper decision making and processing. Moreover, Fig. 1, shows the proposed communication architecture based on CR communication technology, which is regarded as the core technology of fulfilling the demanding communication requirements of the intelligent grid.

A. *Cognitive Communication in HAN*

Several smart devices have been employed in the cognitive HAN topology including, smart meters, gateway, sensors, thermostats, etc. HAN is capable of proving the demand response and energy efficient applications to SG deployment. HAN enables the two-way communication between the devices by utilizing the HAN gateway, which provides the application of cognition capability to enable the network to adapt to any emerging and future radio technologies in the industry. During the feature of two-way communication, the gateway will periodically acquire the energy consumption data from the IED's on the network and transmit such information to the control centre to enable the energy efficient management technique on the network and concurrently receive the data from the NAN and display it on the advanced meters for customer's purposes, and also act as a common point between NAN and HAN. Various communication technologies both wired and wireless, such as ZigBee, PLC, Wifi, etc. are proposed in most of the works in the implementation of SG architecture, however these technologies are subject to interference when operated on the license-free industrial and medical frequency band [25]. So, on the proposed architecture, the GHAN has been utilized as the common node to reduce the interference by detecting the unused frequencies on the network and also allocate the IP addresses and channels to all the devices on the network.

B. *Cognitive Communication in NAN*

Massive amount of data is acquired from the advanced devices utilized in the SG communication network to enable its intelligence features. NAN provides the energy consumption information from the nearby households to control centre. Therefore, to obtain efficient and flexible, delivery and management of the data to ensure proper decision making and processing at data centre, scheduling and allocation of resources should be designed in a strategic way at network management centre. However, the CHAN resolve the issue by prioritizing and categorizing the information according to their status. The issues of interference and spectrum inefficiency prone challenges to the devices utilized in NAN. From CNAN topology, NAN gateways have been employed to serve as the common node between the WAN and HAN. These gateways can enhance the spectrum efficiency and ensure that the QoS requirements are met by distributing the spectrum band among the HAN gateways and also improve the throughput of the NAN [24].

C. *Cognitive Communication in WAN*

WAN is considered as the upper layer of the SG communication architecture that provides broadband communication between substations, NAN's, distributed grid devices and the electric utility [26]. NAN gateways have the ability to interconnect with the control centre as defined, which are connected to the CR base station on the CWAN. The overlay CR based paradigm can be utilized to improve the reliability, security and increased data rates which are suited for WAN and NAN applications, by employing the messages to identify the primary users.

VI. CONCLUSIONS

The work presented on this paper, can serve as a basis towards the proposition of the appropriate ICT architecture/ framework of the successful Smart Grid. A brief review on the recent communication technologies along with their pro's and cons has been presented, with the aim of choosing the suitable communication technology which meets the communication requirements of the SG discussed. A comprehensive understanding is required on the SG ICT network to be able to design and implement a suitable infrastructure for SG. But then 5G and Cognitive Radio, shows promising characteristics for the deployment of SG.

REFERENCES

[1] V C. Güngör, et al, "Smart Grid Technologies: Communication Technologies and Standards", IEEE Trans.Ind. Infor., vol.7, no.4, Nov 2010, pp 529-539.

[2] W. Meng, R. Ma and H-H Chen, "Smart Grid Neighborhood Area Networks: A survey", IEEE Network, Jan/Feb 2014.

[3] X.Fang, S. Misra, G.Xue and D.Yang, " Smart Grid-The New and Improved Power Grid: A survey", IEEE Com.Survey.Tutor.,vol 14,no 4,2012,pp 944-980.

[4] H.Liang et al,"Multiagent Coordination in Microgrids via Wireless Networks" IEEE Wireless Commun,Mag.,vol.19, no , Jun 2012,pp 14-22.

[5] X.Lu, W.Wang, J.Ma, " An Empirical Study of Communication Infrastructures towards the Smart Grid: Design, Implementation and Evaluation", IEEE Trans.vol 4, March 2013, pp 170-183.

[6] M.Albano, L.L Ferreira, and L.M Pinho, " Convergence of Smart Grid ICT Architectures for the Last Mile", IEEE Trans.Indus.Informa.,vol 11,no 1,Feb 2015, pp187-197.

[7] D Ho, Y.Gao, and T. Le-Ngoc "Challenges and research opportunities in wireless communication networks for smart grid", IEEE Wirele.Commun, June 2013

[8] C.Kalalas, L.Thrybom, and J.Alonso-Zarate,"Cellular Communications for Smart Grid Neighborhood Area Networks: A Survey"

[9] J.Gao, J.Wang , B.Wang, and X.Song "Cognitive Radio Based Communication Network Architecture for Smart Grid", March 2012

[10] E. Kabalci and Y.Kabalci, "Smart Grid and their Communication Systems".

[11] G.Fodor, E.Dahlman, G.Mildh, S.Parkvall, N.Reider, G.Miklos, and Z.Turanyi, "Design aspects of network assisted device-to-device communications", IEEE,Comm.Magazine, March 2012.

[12] L.Zheng, S.Parkinson, D.Wang, L.Cai, and C.Crawford, "Energy Efficient Communication Networks Design for Demand Response in Smart Grid", 2011

[13] H.Sun, A.Nallanathan, B.Tan, J.S.Thompson, J.Jiang and H.V.Poor, "Relaying technologies for smart grid communications", IEEE wireless.Commun, December 2012.

[14] N.B.M.Isa, T.C.Wei, and A.H.M.Yatim, "Smart grid technology :communications, power electronics and control systems", ICSEEA, 2015

[15] Y.Yan, Y.Qian, H.Sharif, and D.Tipper, "A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges", IEEE Commun,Surve.Tutor,vol.15, no.1,Jan/Mar 2013,pp5-20

[16] R.Ma, H-H.Chen, Y-R.Huang, and W.Meng,"Smart Grid Communication: Its Challenges and Opportunities", IEEE, Trans.Smart.Grid.vol.4, no.1,March 2013, pp36-46

[17] H.Gözde, M.C. Taplamacıoğlu, M. Arı, and H.Shalaf "4G/LTE Technology for Smart Grid Communication Infrastructure"

[18] F.B. Saghezchi,G.Mantas, J.Ribeiro, M. Al-Rawi∗, S. Mumtaz, J.Rodriguez∗† "Towards a Secure Network Architecture for Smart Grids in 5G Era", 2017.

[19] M.W.Khan, M.Zeeshan, K.Shahzad "On Performance Analysis of IEEE 802.22 PHY for Cognitive Radio based Smart Grid Communications", 2018

[20] P. Kansal, and A.Bose,"Bandwidth and Latency Requirements for Smart Transmission Grid Applications", IEEE Trans. Smart Grid, vol.3,no.3,September 2012.

[21] J.Gao, J.Wang , B.Wang, and X.Song , " Cognitive Radio Based Communication Network Architecture for Smart Grid", 23-25 March, 2012

[22] M. Cosovic, A. Tsitsimelis, D. Vukobratovic, J. Matamoros, and C. Antón-Haro , "5G Mobile Cellular Networks: Enabling Distributed State Estimation for Smart Grids", 2017.

[23] C. Bektas, S. Monhof, F. Kurtz, and C. Wietfeld "Towards 5G: An Empirical Evaluation of Software-Defined End-to-End Network Slicing", 2018.

[24] R. Yu, Y. Zhang, S. Gjessing, C. Yuen, S. Xie, and M.Guizani, Cognitive Radio Based Hierarchical Communications Infrastructure for Smart Grid", Sep/ October 2011

[25] Y. Han, J. Wang, Q. Zhao, and P. Han "Cognitive Information Communication Network for Smart Grid", March 2012.

[26] V. C. Gungor and D. Sahin " Cognitive Radio Networks for Smat Grid Applications", June 2012.