Smart Grid Communication Technologies: A comprehensive Study of Recent Developments and Practical Applications

Israa Jassim Mohammed Karam Jassim Mohammed Alaa Ghadhban Khalaf
Ministry of Higher Education and Scientific Research / Scientific Research Commission
Baghdad-Iraq
E_mail:Israa_Jassim2011@yahoo.com

Abstract

To address concerns like power outages, rising prices, poor power quality, and the need to employ renewable energy sources, the traditional electricity system has evolved into what is now known as the "Smart Grid" (SG). Critical to this goal is the development and rollout of a Smart Grid Communication Network (SGCN) that can reliably and securely transmit data across the grid. With this study, we hope to present a comprehensive overview of SGCN, including its essential characteristics, necessary communication infrastructure, and promising technological developments and practical uses. This study begins with an examination of those communication needs, then provides a high-level overview of SG applications by employing a multi-layer method and separating the communication layer into Home Area Networks, Neighbor Area Networks, and Wide Area Networks. Next, the current wireless and wired communication techniques, as well as new techniques like Cognitive Radio (CR), TV White Spaces (TVWS), and Smart Utility Networks (SUN), that are ideal for the SG environment, are compared in detail. Finally, the proposed CR based network architecture for SGCN is presented, along with its salient features. After that, the article ends with a few suggestions for how to move forward.

Keywords: Cognitive Radio, Network, SGCN and SG.

تكنولوجيات الاتصالات في الشبكات الذكية: دراسة شاملة للتطورات الحديثة والتطبيقات العملية

اسراء جاسم محمد كرم جاسم محمد علاء غضبان خلف
وزارة التعليم العالي والبحث العلمي / هيئة البحث العلمي
بغداد – العراق

الخلاصة

لمعالجة المخاوف مثل انقطاع التيار الكهربائي، وارتفاع الأسعار، وضعف جودة الطاقة، والحاجة إلى استخدام مصادر الطاقة المتجددة، تطور نظام الكهرباء التقليدي إلى ما يعرف الآن باسم الشبكة الذكية، ممكن تحقيق هذا الهدف بتطوير ونشر شبكة اتصالات الشبكة الذكية التي يمكنها نقل البيانات بشكل موثوق وآمن عبر الشبكة. من خلال هذه الدراسة، نأمل أن نقدم نظرة عامة وشاملة عن شبكة اتصالات الشبكة الذكية، بما في ذلك خصائصها الأساسية، والبنية التحتية للاتصالات الضرورية، والتطورات التكنولوجية الواعدة واستخدامات شبكة. تبدأ هذه الدراسة بفحص احتياجات الاتصال هذه، ثم تقدم نظرة عامة عالية المستوى على تطبيقات الذكية متعددة الطبقات الاتصال إلى شبكات المنطقة المحلية وشبكات المنطقة المجاورة وشبكات المنطقة الواسعة. بعد ذلك، تتم مقارنة تقنيات الاتصالات السلكية واللاسلكية الحالية، فضلاً عن التقنيات الجديدة مثل الراديو المعرفي، ومساحات التلفزيون البيضاء وشبكات المرافق الذكية، والتي تعتبر مثالية لبيئة الشبكة الذكية. أخيرًا، يتم تقديم بنية الشبكة المقترحة القائمة على شبكة اتصالات الشبكة الذكية، جنبًا إلى جنب مع ميزاتها البارزة. بعد ذلك، تنتهي المقالة ببعض الاقتراحات حول كيفية المضي قدمًا.

الكلمات المفتاحية: الراديو المعرفي ، الشبكة، شبكة الاتصال الذكية و الشبكة الذكية.

Introduction

The traditional power grid was built to satisfy the needs of the last century, with central power generation and no automation in mind. Excessive power capacity with single directional power flow from fuel based or hydropower facilities to consumer was the sole approach to improve dependability. All other industries have been disrupted by the spread of computing and communication technology, but the electric grid has continued to be run in much the same way for decades. Many countries have had to optimize their electric grids in terms of alternative, efficiency, and reliability energy resources in response to rising demand for widespread blackouts, electricity, frequent instances of electricity alarming and shortages increases in electricity power quality, prices, and environmental hazards. Due to rising consumer expectations and other factors, a new, more efficient electric power infrastructure the "smart grid" (SG) is now required (Quang, *et al*., 2013). SG is defined as a "computerized, extensively dispersed energy delivery network emission typified by a two-way flow of electricity and information, capable of monitoring and responding to changes in everything from power plants to consumer preferences to individual appliances" (IEEE, 2005). SG's key goals are the efficient generation and distribution of power, the optimization of energy use by customers via bi-directional flow of information, and the reduction of carbon dioxide via the use of green energy sources. The bi-directional flow of information and electricity in the SG enables different intelligent techniques like home/building automation, meter reading distribution, and restoration management (Murat, *et al*., 2014 and Massachusetts, 2011). As a result, it is the grid's efficient bi-directional communication that makes it smart. This study reviews technical and theoretical aspects of creating a Smart Grid communication network, in order to compare wired and from far technologies and significant applications.

Literature Review

Various streaming technology issues in SG are discussed in (Honggang, *et al.*, 2013). A future smart grid environment related to multimedia communication is outlined, and the communication and solutions of CR networking are explored. In (Yan, *et al.*, 2012), the authors describe a new M2M communication paradigm and an energy-efficient spectrum finding scheme. They have demonstrated mathematically that SG is more reliable and uses less energy (Gungor and Sahin, 2012). The main obstacles and unresolved questions related to the supply of CR-based intelligent Grid applications are discussed, along with a comprehensive evaluation of Smart Grid characteristics and architectures to do so. Cognitive radio applications, interoperability of standards, and cyber security in SG communications are just some of the topics covered in (Ruofei, *et al*., 2013).

According to the various traffic kinds of SG, such as control commands, multimedia sensing data, and meter readings, the authors of (Jingfang, *et al.*,

2013) have presented a priority-based traffic scheduling approach for CR based smart grid systems. In (Skein, et al., 2014), we offer a novel approach to channel estimation and noise + interference power estimation using the IEEE 802.22 standard. Improvements in both capacity and bit error rate (BER) were seen in simulations of a smart grid system using the MMSE beam former. For multimedia communications in a smart grid setting, see (Shengrong and Yu, 2014), which proposes a green cognitive mobile network based on small cells.

(Rong, *et al.*, 2014) presents an intriguing solution to the problem of secondary user characteristics in cognitive radio by introducing a novel spectrum sharing technology known Hybrid Spectrum Access (HSA), which is based on clever usage of both licensed-free and licenced frequency bands for SG communication. Athar Ali Khan et al appears in (Athar, *et al*., 2016).

In (Vega, *et al.*, 2016), the authors discuss a new model for HEMSs in which the end user actively participates in the electrical value chain, after reviewing nearly 70 existing models. In (Omar and Haitham, 2016), the authors provide a high-level summary of Smart Grid customer acceptance and participation, as well as a summary of some effective Demand Response programmes. In (Zahurul, *et al.*, 2015), we have a case study on SG advancement in underdeveloped nations and a presentation of Integrating Distributed Renewable Generation using Wireless Sensor Networks in Malaysia.

A survey of behind the meters management (BTMM) in Singapore was carried out and discussed in (Islam and Taha, 2016). Additionally, a case study showcasing the deployment of the system was conducted at the same time. A study of the various control, communication, integration, and metering (ICCM) techniques used Singapore may be found in (Reddy, *et al*., 2014). A survey on the smart communication technology, metering, and Software or hardware security requirements was published by the authors in (Yasin, 2015). (Ali, 2016) investigates a thorough selection of recent research articles on wide area control and stability in SG as well as architectural network models that are appropriate for Wide Area Systems. These articles cover a variety of subject.

Materials and Methods

Radio Transceiver (RT)

The SG's potential benefits can only be realized with a communication infrastructure that is not only secure and dependable, but also meets the SG's communication requirements on a budget (SGCN). Due to the huge number of heterogeneous devices spread out across significant distances and with varying quality-of-service (QoS) needs, designing and deploying an SGCN is a difficult undertaking. Data, reliability, latency limits, and traffic patterns are all key factors to consider when designing an SGCN because the nature of network traffic for bi-directional information flow is quite different from that of ordinary communication networks. As is common practice in the research, we use a five-layer model to understand SG multilayered design as shown in Figure1.

These levels include Power generation, transmission, distribution, and consumption all fall within the purview of the "power system layer. “This layer is responsible for power-related management tasks like monitoring and controlling (Murat, *et al*., 2014). The SGCN's "Communication Layer" which is in charge of both one-way and two-way exchanges, Authentication of users, as well as privacy and integrity for customers, are provided by the security layer. Application layer: enabling a wide range of SG applications for use by end users and service providers in managing and keeping tabs on infrastructure. Consider the following scenario: an automatic meter reading of consumed electricity units is to be performed. Layer application will enable automatic meters reading applications.

Figure (1) Multilayer System of SG (Murat, *et al*., 2014)

The layer of power system will supply electricity to user. Smart meters will function at the Power control layer, which will monitor the power consumption reading. The layer of communication will transport data from user premise to the utility company. The security layer will be in charge of all security features pertaining to data privacy and customer confidentiality. One of the most important layers in the SG multilayer architecture is the communication layer. As a result, the communication layer will be the primary focus of this paper. The layer of communication is also classified on the basis of range, data rate, and coverage area into: Wide Area Network (WAN), Neighborhood Area Networks (NAN), and Home Area Network (HAN) (Murat, *et al*., 2014) as shown in Figure 2.

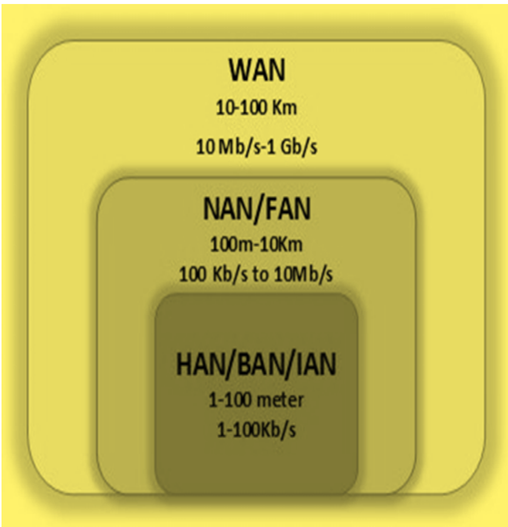

Figure (2) Data Rate and Approximate Coverage Requirements for WAN, NAN, and HAN

Local Area Service (LAS)

Also known as a BAN or IAN, is a network that extends to the customer's location and connects the many sensor-equipped smart devices there to the smart meters so that energy can be used more efficiently.

From appliances like air conditioners, heaters, washing machines, and the like by careful monitoring and management of energy usage. It's possible that it will also be able to handle other functions, such as enabling prepaid electricity, showing the number of units used, the amount owed, and the time of day when electricity use is at its peak, etc. Smart meters (SMs) serve as communication gateways between HANs and NANs, in addition to monitoring and controlling all smart devices within the customer premises. HANs are capable of covering regions as little as 100 m^2 and as large as 200 m^2 with data speeds of 10 to 100 kb/s.

Regional Area Network (RAN)

Covers both the distribution and transmission layers, hence the name "Field Area Network" (FAN). The SGCN core is responsible for moving enormous amounts of varied information between the WAN's service providers and the HAN's smart devices. SMs in the Customer domain of the NAN support a wide range of SG applications, including those dealing with power outages, distribution automation, power quality monitoring, and among others. Each SM in a NAN cluster may require anything from 100 Kb/s to 10Mb/s of bandwidth, and the number of SMs in a cluster may range from a few hundred to several thousand, all depending on the power grid topology (centralized/distributed) and the communication protocol employed.

Broadband Network (BN)

Since it aggregates data from numerous NANs and transmits it to the Control Centre, SGCN serves as its communication backbone. Power plants, substations, control rooms, distribution grids, transmission, distributed energy resource stations, and distribution grids and so on can all connect to one another over vast distances using this system. A large amount of data, potentially thousands of gigabytes, is transmitted across the WAN to the control Centre, therefore the usual data rate required may range from 10 to 100 Mb/s over a distance of several hundred kilometers.

Figure 3 (Emilio, *et al.*, 2013) provides a high-level overview of a hybrid (Wired and wireless) SGCN, and the underlying technologies are discussed in greater detail in the following sections:

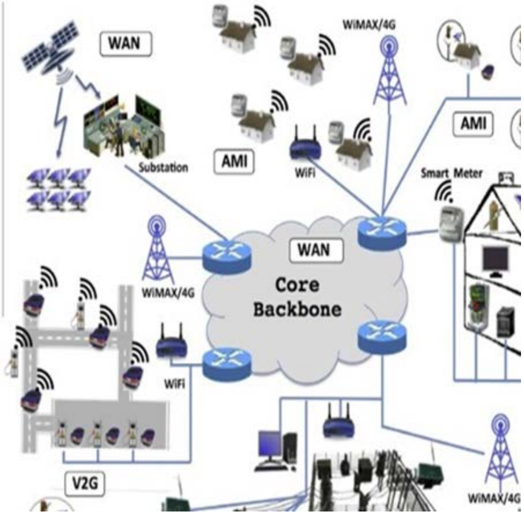

Figure (3) Example of Hybrid SGCN (Emilio, *et al.*, 2013)

A. Justification: The Role of Cognitive Radio (CR) in Smart Grids

The information that must be transferred through the SGCN's network of communication nodes is immense in size and scope, but also very different from that of more traditional networks.

We can priorities data on the basis of its delay tolerance. When comparing the data reliability and latency requirements of different types of transmissions, it is clear that data conveying control orders, such power scheduling, have higher standards. With the inclusion of multimedia monitoring and surveillance data, the volume of data is estimated to be in the range of thousands of gigabytes.

Therefore, the need for bandwidth and network resources is growing to accommodate this massive amount of data. To carry less delay-sensitive data over the communication network, CR is the optimal/key technology because the desirable wireless spectrum, which has better propagation characteristics, is already filled and unduly congested. For this very much reason, CR based standards are already in the business specifically for Smart Grid environment. However, later in this section, we review the literature on CR in the Smart Grid area.

B. The Major Aims and Achievements of This Study

The primary goal of this article is to define critical needs for the design of SGCN, which will lead to the Various wireless structures and techniques are deployed, and a workable open architecture is presented here for SGCN that is based on CR. The following are the contributions of this article toward this end:

We provide review of existing communication techniques, both wireless and wired, including some of the modern techniques, like IEEE 802.22 WRAN, IEEE 802.11af, and Intelligent Electricity Network (SUN); we also identify essential network requirement on the basis of which technological devices are evaluated. Key obstacles, unresolved concerns, and prospective future research topics are outlined, and open end to end topology for SGCN based on Cognitive radios is proposed (Alexander, *et al*.,2010).

C. Content Formatting

As for the rest of the paper, its structure is as follows: The essential components for the construction of SGCN are discussed in Section II. In Section III, we provide a high-level review of SG applications and a case study to help you estimate the volume of data created by your specific use case. In Section IV, we present a thorough examination of some promising current and future wired and wireless communication methods. In Section Vi have attempted a brief summary of the difficulties encountered while developing SGCN. We propose a CR-based design for SGCN in Section VI. The remaining questions, difficulties, and potential new lines of inquiry are discussed in Section VII. Section VIII concludes our article by summarizing our findings and conclusions.

Microgrid Information Network Architecture (RT)

The following are necessary for a Smart Grid Communication Network (SGCN) to be implemented in practice: Meeting the data rate requirement of SG communications Meeting the latency and reliability requirement of SG communications Facilitating the use of SG applications Addressing the issue of scarce radio spectrum

Key concerns in SGCN design include (Emilio, *et al.*, 2013) Which communication protocols and network architectures are best for connecting disjointed nodes?

How does the choice of communication protocol and grid location impact the network topology?

What are the best communication protocols to use when taking into account SG's varied ecosystem?

Because SGs can operate in a wide variety of contexts, it is unlikely that a universal answer can be provided to the questions posed above. However, the most of the system needs are universal.

A. Equipment Prerequisites

System needs must be defined before a comparison of HAN, NAN, and WAN communication technologies can begin. Several important needs for SG have been mentioned in publications by research institutions, utility providers, and national governments (U.S., 2010, Daoud and Fernando, 2011). Two primary categories will be discussed below:

Measurable, quantitative criteria; they are the KPIs for your communications system.

For both service providers and end users, it is important to have a system that meets qualitative standards.

B. Statistical Definitions

To ensure the quantitative criteria are met, there are three outcome measures (KPIs) that can be tracked: One of the most crucial constraints for control and safety functions in any power system is latency, which is a measuring of delay.

For instance, in a distribution automation system, the transfer of measurements from IEDs to a data aggregator may need to have a maximum delay of no more than 4 milliseconds.

However, the information transfer delay between DAPs and control centers might range from 68ms to 12ms (IEEE, 2005). In a similar vein, fewer time-sensitive applications can tolerate somewhat higher network delays, such as automatic meter readings (AMRs), firmware upgrades, and software updates.

Accordingly, the communication system employed must meet the lower latency requirements (Wang, *et al.*, 2011) for the time important data.

Reliability: Some important functions of smart grid infrastructure cannot be assured without a highly dependable SGCN. A network failure can occur due to a variety of factors such as link /node failure, gateway/device malfunctioning, over-loading, and so on; hence, redundancy is crucial for critical links and devices / gateways / servers. Data in the SG context might also be quite different in terms of criticality. Some messages cannot accept any loss and must be transmitted quickly, whilst others can suffer losses very seldom (Niyato, *et al.*, 2011). As a result, applications must be able to priorities their data for transmission based on the level of criticality.

Data Rate: When it comes to SGCN, the data rate requirements change depending on whether the link is a Local Area Network (LAN), a Wide Area Network (WAN), or the internet. The previous section showed a typical requirement for WAN, HAN, and NAN. However, due to the fact that it may be necessary to convey multimedia data (such as video surveillance of site), the necessity for a sufficient data rate for the communication link is rapidly increasing. Therefore, it is important to optimize communication networks between nodes in order to not only increase the data flow but also to decrease delays and packet losses (GAO, *et al.*, 2012).

Descriptive Specifications

The following are required network characteristics for an SGCN: In an SG setting, the number of customers can easily reach millions and grow exponentially on a regular basis, so the need for scalability is obvious. One highly sought-after feature of SG is its capacity to scale in response to unexpectedly high levels of demand for data or services. The ability to scale up or down a network and deploy alternative configurations based on physical needs is another fundamental feature of every network.

Scalability (GAO, *et al*., 2012) also includes the ability to increase the size of the routing table and the Communication resources in the event that new nodes are added to the network. Smart grids can benefit from distributed communication architectures because of this.

With so many devices using a wide variety of networking and communication standards, it's clear that SGCN requires a high level of interoperability between them. Therefore, ensuring compatibility between different forms of communication and devices is essential (NIST, 2010). One could put in place a communication gateway to connect segments that use various communication technologies or standards It is important to note that interoperability is critical in terms of both networks and apps, which necessitates standards to ensure that data exchanged between applications has the same meaning in each application.

The term "flexibility" can have a broad meaning in SGCN. Provisioning Hetnet services with varying degrees of availability and latency is essential. It also advises that SGCN have multiple communication models, such as a multipoint to point (MP2P) model for monitoring applications and a point-to-multipoint (P2MP) model for disseminating network commands and configuration info to multiple devices (Wang, *et al*., 2011). Because SGCN must meet the needs of a wide variety of applications, the networking technologies and protocols it employs must be very flexible and adaptable.

Protection from cyber-attacks and customer confidentiality are two important aspects of network security that SGCN must provide (Khurana, *et al*., 2010). For instance, SGCN must safeguard the privacy of each customer unique load profile and metering data. Security mechanisms such as authorized authentication, intrusion detection, encryption of sensitive data, and trust can help SGCN identify and eliminate these dangers (Wang, *et al*., 2011).

Benefits of the Cloud Computing

A part from quantitative and qualitative requirements discussed in previous section; it is also very important to know that what sort of data is contained in data that is to be carried. Therefore, one may get an idea about data rate and latency attributes of the technologies to be chosen.

A. HAN Technologies

Building services management, which involves transmitting the readings/ measurements from an IED to a controller at the customer location, are examples of applications common in the Business Area N/W (BAN), Industrial Area N/W (IAN), and Home Area N/W (HAN).

Therefore, HAN calls for reliable communication channels with low power requirements, modest data speeds, and limited service areas.

Wi-Fi, ZigBee, Bluetooth, power line carrier, Z-Wave, and Ethernet are usually utilized to support BAN/IAN/HAN application because they meet the requirements of supplying data rate of up to 100 kbps with small coverage distance (up to 100 m).

B. Benefits of NAN

Multiple NAN applications necessitate the transmission of data from a large number of homes' smart meters (SMs) to data collectors' substations or vice versa, necessitating data rates of 100 Kb/s to 10 Mb/s, low to high latency, and coverage distances of up to a few kilobars. Wi-Fi, ZigBee, TOEW, DSL, and cellular technologies such as 3G/4G and WiMAX may all be applicable, based on on the specifics of the situation. To evaluate the typical data amount and latency needed by most applications, we refer to (Murat, *et al.*, 2014), which provides a full study for the NAN application.

C.WAN Applications

Real-time applications for the specific purpose of monitoring, control, protection are supported a WAN, making it the next-generation solution to ease the planning, protection, and operation of the entire system. This collection of time-sensitive data is quite large and requires a high degree of reliability.

The total amount of data to be transmitted across WAN is projected to be in the thousands of gigabytes level. Communication technologies offering data rates of 10 Mbps–1 Gbps up to range (100 km) are suitable for control, monitoring, and protection applications in WAN, which involve conveying a large volume of data to different nodes at higher data rates (typically 10 to 100Mb/s) with low latency to allow stability control. Because of its low latency and increased data rates over longer distances, optical communication is a leading choice for use between substations (Transmission/Distribution) and control stations. Because of their large coverage range and better throughput, cellular technologies such as 4G LTE and WiMAX are also appropriate. Satellite communication can also be utilized for redundancy and backup communication in faraway locations.

RT Wireless Communications

Technology for transmitting data can be roughly divided into two categories: wired and wireless. If you're looking at bandwidth, cost, dependability, security, maintenance, and not having to pay for the spectrum, wired solutions are the clear winner over wireless ones.

However, wireless connectivity is currently popular because it is easy to expand, modify, and rearrange (from operators' perspective) and mobility (most attractive feature for user).

Connected Tools:

Overhead Wires Connectivity (SCGN), Optical Connections (OC), and Digital Subscriber Line (DSL) are three of the most prominent rival wired technologies (DSL), so it is provides a comparison of these various technological approaches.

Telecommunication over Electric Wires (TOEW)

Given its obvious benefits, TOEW technology was one of the first to be employed for automating the energy grid. TOEW technology transmits a modulated carrier over an already existing power line connection, allowing for bi-directional communication.

Narrow band TOEW (NB-TOEW) and Broadband TOEW are the two primary categories of (BB-TOEW) It is possible to use the NB-TOEW on frequencies between 3 and 500 kHz. Low Data Rate NB-TOEW and High Data Rate NB-TOEW are two subcategories. Data rates of up to 10 kbps can be achieved with Low Data Rate NB-TOEW thanks to the use of a single carrier, whereas data rates of less than 1 Mbps can be achieved with High Data Rate NB-TOEW thanks to the use of multiple carriers. However, BB-TOEW technology may provide throughputs of several hundred megabits per second (Mbps) over a frequency range of 2 to 250 MHz. Multiple protocols for TOEW are at odds with one another (draft). TOEW is best suited for applications like as Substation Automation, AMI Backhaul, Remote Monitoring, and Distribution Automation in the SG environment. As a result, TOEW can be considered a viable solution for SG (Ahmad and Sajjad, 2015). Because power lines are unshielded, there are several challenges with signal propagation along power cables, such as disruptive interference from power signals, devices, or external electromagnetic interference (Emilio, *et al*., 2013). Furthermore, the cost is significant due to the required specialist equipment.

Conclusion

The transition from traditional power grids to Smart Grids (SG) is driven by the need to address challenges such as load shedding, environmental impacts of fuel consumption, power quality, and the integration of advanced control and surveillance systems. At the heart of SG's intelligence is the requirement for two-way communication, enabling real-time data exchange and adaptive grid management. To meet this demand, wireless communication technologies play a crucial role, supporting the diverse needs of the grid while ensuring scalability and flexibility. The significant challenge of transferring large volumes of data—often in the range of terabytes—across the grid is compounded by the limitations of traditional communication networks. In this context, Cognitive Radio (CR) presents a promising solution by enhancing spectral efficiency and enabling more efficient use of licensed frequency bands. By leveraging CR, the Smart Grid can improve its communication capacity and resilience, particularly in environments with high data traffic.

This study has reviewed both the technical and theoretical aspects of building a Smart Grid Communication Network (SGCN), comparing wired and wireless technologies and exploring their respective advantages and limitations. A key contribution of this work is the proposal of a scalable and adaptable CR-based network architecture, which aligns with the latest technologies and standards, providing a flexible framework for future SG deployments.

While significant progress has been made, numerous technical challenges remain, particularly in terms of ensuring reliable and secure communication in dynamic SG environments. However, the insights presented in this study lay the groundwork for further exploration of CR in Smart Grid applications, offering a pathway to overcoming these challenges and unlocking the full potential of the Smart Grid.

In conclusion, the integration of Cognitive Radio into Smart Grid communication systems represents an exciting frontier in the evolution of energy networks. Continued research and development will be essential in addressing the remaining technical obstacles and ensuring that Smart Grids can meet the future energy demands of a connected, sustainable world.

References

Ahmad Usman and Sajjad Haider Shami.,(2011), Evolution of Communication Technologies for Smart Grid Applications, Renewable and Sustainable Journal.

Alexander M. Wyglinski, Maziar Nekovee, and Thomas Hou Y.(2010), Cognitive Radio Communications and Networks: Principles and Practice, Academic Press (ELSEVIER)..

Ali S.M.(2016). Wide Area Smart Grid Architectural Model and Control: A Survey, Journal of Renewable and Sustainable Energy Reviews (JRSER), ELSEVIER.

Angela Sara Cacciapuoti, Marcello Caleffi, Francesco Marino, and Luigi Paura.,(2016). Mobile Smart Grids: Exploiting the TV White Space in Urban Scenarios, IEEE Access,.

Athar Ali Khan, Mubashir Husain Rehmani, and Martin Reisslein.(2016). Cognitive Radio for Smart Grids: Survey of Architectures, Spectrum Sensing Mechanism and Networking Protocols, IEEE Communication Surveys and Tutorials,

Daoud M. and Fernando X.(2011). On The Communication Requirements for The Smart Grid, Energy and Power Engineering, Volume 3, PP: 53–60.

Emilio Ancillotti, Raffaele Bruno, and Marco Conti.(2013). The Role of Communication Systems in Smart Grids: Architectures, Technical Solutions and Research Challenge, Computer Vol Communications ELSEVIER, September.

GAO J., Xiao Y., Liu J., Liang W., and Chen C. (2012). A Survey of Communication/Networking in Smart Grids, Future Generation. Computer Systems (ELSEVIER), Volume 28, pp: 391–404.

Gungor, V.C. and Sahin, D. (2012). Cognitive Radio Networks for Smart Grid Applications: A Promising Technology to Overcome Spectrum Inefficiency, Vehicular Technology Magazine, IEEE Year: 2012, Volume: 7, Issue: 2, pp: 41– 46.

Honggang Wang, Yi Qian, and Sharif, H (2013). Multimedia Communications Over Cognitive Radio Networks for Smart Grid Applications, Wireless Communications, IEEE, Volume: 20, Issue: 4 pp: 125 – 132.

IEEE 1646, IEEE Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation, 2005.

IEEE Std. P2030. Draft Guide for Smart Grid of Energy Technology and Information Technology Operation with the Electric Power System (EPS), And End-Use Applications and Loads, 2011.

Islam Safak Bayram and Taha Selim Ustun.(2016). A Survey on Behind the Meter Energy Management Systems in Smart Grid, Journal of Renewable and Sustainable Energy Reviews (JRSER), ELSEVIER.

Jingfang Huang, Honggang Wang, Yi Qian, and Chonggang Wang. (2013). Priority-Based Traffic Scheduling and Utility Optimization for Cognitive Radio Communication Infrastructure-Based Smart Grid, Smart Grid, IEEE

Transactions on, Volume: 4, Issue: 1, pp: 78 – 86.

Khurana H., Hadley M., Lu N., and Frincke D. (2010). Smart-Grid Security Issues, IEEE Security Privacy, Volume 8, pp:81–85.

Maria Lorena Tuballa and Michael Lochinvar Abundo. (2016). A Review of The Development of Smart Grid Technologies, Journal of Renewable and Sustainable Energy Reviews (JRSER), ELSEVIER,.

Massachusetts Institute of Technology. (2011). The Future of the Electric Grid, http://health.cat/open.php?url=http://mitei.mit.edu/system/files/Electric_Grid_Full_Report.pdf.

Murat Kuzlu, Manisa Pipattanasomporn, and Saifur Rahman. (2014). Communication Network Requirements for Major Smart Grid Applications in HAN, NAN and WAN, Computer Networks (ELSEVIER).

Nazmus S. Nafi, Khandakar Ahmed, Mark A. Gregory, and Manoj Datta ,(2016). A Survey of Smart Grid Architectures, Applications, Benefits and Standardization, Journal of Network and Computer Applications, ELSEVIER, Oct.

NIST (National Institute of Standards and Technology), (2010) NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0, January.

Niyato D., Wang P., Han Z., and Hossain E, (2011). Impact of Packet Loss on Power Demand Estimation and Power Supply Cost in Smart Grid, in: Proc. of IEEE WCNC, Volume 11, pp. 2024– 2029.

Omar Ellabban and Haitham Abu-Rub, (2016). Smart Grid Customers' Acceptance and Engagement: An Overview, Journal of Renewable and Sustainable Energy Reviews (JRSER), ELSEVIER, June.

Quang dung HO, Yue Gao, and Tho Le-Ngoc., (2013). Challenges and Research Opportunities in Wireless Communication Networks for Smart, Wireless Communications, IEEE, volume 20, issue 3.

Reddy K.S et.al.,(2014). A Review of Integration, Control, Communication and Metering (ICCM) of Renewable Energy based Smart Grid, Journal of Renewable and Sustainable Energy Reviews (JRSER), ELSEVIER.

Rong Yu, Chaorui Zhang, Xing Zhang, Liang Zhou, and Kun Yang. Hybrid Spectrum Access in Cognitive-Radio-Based Smart-Grid Communications Systems, Systems Journal, IEEE, Volume 8, Issue 2, pp: 577– 587 (2014).

Ruofei Ma, Hsiao-Hwa Chen, Yu-Ren Huang, and Weixiao Meng,(2013). “Smart Grid Communication: Its Challenges and Opportunities”, Smart Grid, IEEE Transactions on Year: Volume: 4, Issue: 1 Pages: 36 – 46.

Sekchin Chang, Nagothu, K., Kelley B., and Jamshidi, M.M, (2014). A Beamforming Approach to Smart Grid Systems Based on Cloud Cognitive Radio, Systems Journal, IEEE, Volume 8, Issue 2, pp: 461 – 470.

Shengrong Bu and Yu F.R, (2014). Green Cognitive Mobile Networks with Small Cells for Multimedia Communications in the Smart Grid Environment, Vehicular Technology, IEEE Transactions, Volume 63, Issue 5, pp: 2115 – 2126.

U.S. Department of Energy (DOE). Communication Requirements of Smart Grid Technologies,(2010), http://energy.gov/gc/ downloads/ communications- requirements -smart-grid- technologies.

Vega A.M., Santamaria F., and Rivas E,(2015). Modeling for home electric management: A review, Journal of Renewable and energy Sustainable Energy Reviews (JRSER), ELSEVIER,.

Wang W., Xu Y., and Khanna M. A,(2011). Survey on The Communication Architectures in Smart Grid, Computer Networks (ELSEVIER), Volume 55, Issue 15, Pp: 3604–3629.

Yan Zhang, Rong Yu, Nekovee, M., and Yi Liu,(2012). Cognitive Machine-to-Machine Communications: Visions and Potentials for The Smart Grid, Network, IEEE, Volume 26, Issue 3, pp: 6 – 13.

Yasin Kabalci,(2015). A Survey on Smart Metering and Smart Grid Communication, Journal of Renewable and Sustainable Energy Reviews (JRSER), ELSEVIER, December.

Zahurul S. et.al.(2015). Future Strategic Plan Analysis for Integrating Distributed Renewable Generation to Smart Grid Through Wireless Sensor Network: Malaysia Prospect, Journal of Renewable and Sustainable Energy Reviews (JRSER), ELSEVIER, September.