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A Review on Communication Aspects of Demand Response Management for Future 5G IoT- Based Smart Grids

SAHAR AHMADZADEH, GERARD PARR, AND WANQING ZHAO, (Member, IEEE)
School of Computing Sciences, University of East Anglia, Norwich NR4 7TJ, U.K.

Corresponding author: Sahar Ahmadzadeh (sah.ahmadzadeh@gmail.com)

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ABSTRACT In recent power grids, the need for having a two-way flow of information and electricity is crucial. This provides the opportunity for suppliers and customers to better communicate with each other by shifting traditional power grids to smart grids (SGs). In this paper, demand response management (DRM) is investigated as it plays an important role in SGs to prevent blackouts and provide economic and environmental benefits for both end-users and energy providers. In modern power grids, the development of communication networks has enhanced DRM programmes and made the grid smarter. In particular, with progresses in the 5G Internet of Things (IoT), the infrastructure for DRM programmes is improved with fast data transfer, higher reliability, increased security, lower power consumption, and a massive number of connections. Therefore, this paper provides a comprehensive review of potential applications of 5G IoT technologies as well as the computational and analytical algorithms applied for DRM programmes in SGs. The review holistically brings together sensing, communication, and computing (optimization, prediction), areas usually studied in a scattered way. A broad discussion on various DRM programmes in different layers of enhanced 5G IoT based SGs is given, paying particular attention to advances in machine learning (ML) and deep learning (DL) algorithms alongside challenges in security, reliability, and other factors that have a role in SGs' performance.

INDEX TERMS Smart grid, demand response management, 5G, Internet of Things.

I. INTRODUCTION

The concept of SGs started with the notion of advanced metering infrastructure (AMI) to improve demand-side management, energy efficiency, and a self-healing electrical grid, where AMI enables the communication between the utility control center and smart meters. A SG improves supply, reliability, and response to natural disasters and increases bidirectional interaction between grid components. Historically, increasing the efficiency of system operation and the existing investment in the generation and transport of electricity has been the key driver for introducing DRM programmes. Implementation of AMI and other SG technologies will further increase the use of DRM resources (ie.smart measurement devices such as smart meters and AMI) in everyday operations. Figure 1 schematically depicts the factors in relation to the new ongoing SG paradigm related to three key factors including:

- environmental factors (e.g. green house gasses, renewables)
- Reliability issues that affects on system performance (e.g. variable generation, distributed resources, and capacity limitations)
- operational issues (e.g. operational efficiency, customer satisfaction, supply economies)

Where DRM on the top manages the interaction between different ingredients of SGs to support each side by maximizing it's benefit in order to enhance the performance of the whole grid. Facing the increasing demands and the need for suitable programs to enhance the efficiency of the SG, the importance of DRM can be increasingly highlighted than beforehand. In this way, advanced telecommunication technologies play an crucial role to provide reliable and low-latency networks

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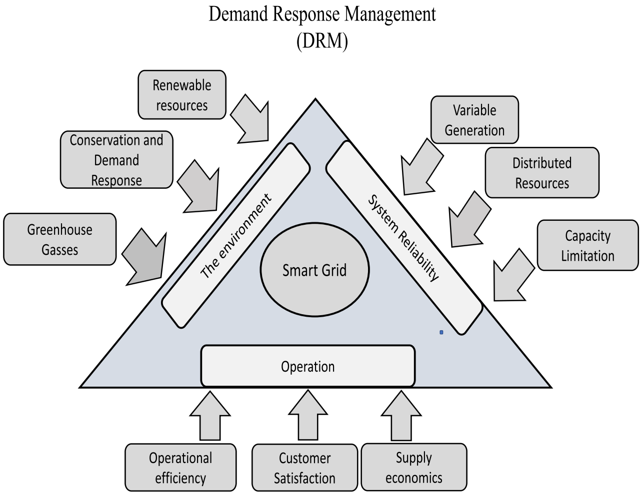

FIGURE 1. DRM as one of the industry drivers of SG.

through 5G IoT which is under deployment in different countries around the globe.

To understand the importance of DRM programmes and the role of 5G IoT in SGs, this paper provides a review of DRM with a focus on potential applications of 5G technologies and progresses in advanced Machine Learning (ML) and Deep Learning (DL) algorithms.

According to [1] DRM programmes are divided into price-based and incentive-based programs. These programs are universally applied in many residential areas [2]. In SGs IoT systems provide the opportunity for bidirectional interactions between various parts of a SG. This offers the flexibility to run different DRM programmes. Literature in [3]–[5] explained contract based DRM in SGs with a focus on optimization approaches. DRM is closely related to concepts such as remote control and automatic communication, where 5G technologies play an important role. Examples of advantages of 5G over previous generations include improved reliability, security, transfer speed, power consumption, as well as the increased number of connections [6], [7]. The frequency spectrum of 5G is in the range of GHz which is much higher than previous generations. Also, 5G bandwidths are higher than the previous 1G-4G. According to [8] 5G technologies are considered the most important driver for the emerging global IoT. There is a number of literature that studies the importance of 5G for IoT. For instance, in [9] potential applications of 5G in DRM programmes are investigated.

With respect to recent advanced communication systems, fog computing is considered to provide massive connectivity and fast communication. For instance, [10] studies application of fog and cloud computing for electrical vehicles (EVs) to communicate faster with power systems. In [11], [12] the application of data slicing in 5G is used for bidirectional data transfer between EVs and electricity providers. However, as 5G is a new technology, effort is needed to fully exploit its benefits in DRM programmes.

A. COVERAGE OF THIS SURVEY ARTICLE

The main contributions of this research are summarized as:

- In-depth discussion of telecommunication aspects of DRM in the SG with emphasize on advanced 5G IoT-based technologies
- Review on machine learning and optimization algorithms applied for DRM in SGs

In this paper the above-mentioned aspects are combined with a review of DRM models and algorithms in four layers of SG consisting of generation, transmission, distribution, and end-users. Some DRM challenges in SG have also been identified to gain a broad understanding of the subject area. Figure 2, illustrates the road map of this paper.

B. REVIEW OF RELATED SURVEY ARTICLES

There have been a few review articles providing an in-depth survey of DRM based on 5G-IoT enabled technologies. DRM can be investigated from different perspectives such as algorithms, communication aspects, and programs. However, to the best of our knowledge there is not a holistic review bringing together all these components and analysing the interactions or interdependencies between them. In [6], [13] the communication aspects of DRM was studied. This research gave a survey on the potential of applying 5G network-based IoT for DRM in the SGs. The concept of DRM, reliability, and security issues related to SG based on typical application scenarios of 5G IoT was investigated. However, this paper did not cover DRM in different layers of SG and DRM algorithms. Moreover, challenges that impact the performance of the network were not covered.

Peak load shaving under demand-side management was comprehensively reviewed in [14] with a focus on energy management approaches in a smart IoT based environment. However, [14] did not cover 5G and telecommunication aspects of DRM. With respect to the algorithms and artificial intelligence techniques for DRM. Reference [15] provides state of the art review on AI techniques for distributed SG. However, this paper failed to cover the telecommunication aspects.

With respect to modeling the load in the SG [16] provided a review on a multi-energy management system with a focus on a variety of loads. In [17] a review of the barriers and enablers of DRM in SG was provided. Focusing on telecommunication aspects of DRM [18] discussed the applications of the integration of 5G and SG. This paper reviewed 5G key technologies such as mobile edge computing, computational caching techniques, network slicing techniques, and 5G's value to power service access, transmission, and core networks slicing architecture. Also, [19] studied cognitive radio SG communication infrastructure systems. The main objective was to investigate emerging technologies such as cognitive radio networks (CRNs) as part of the 5G mobile technology for reliable communication in SG networks. Furthermore, a hybrid architecture based on the combination of fog computing and cloud computing was proposed. In this architecture, real-time latency-sensitive information is given

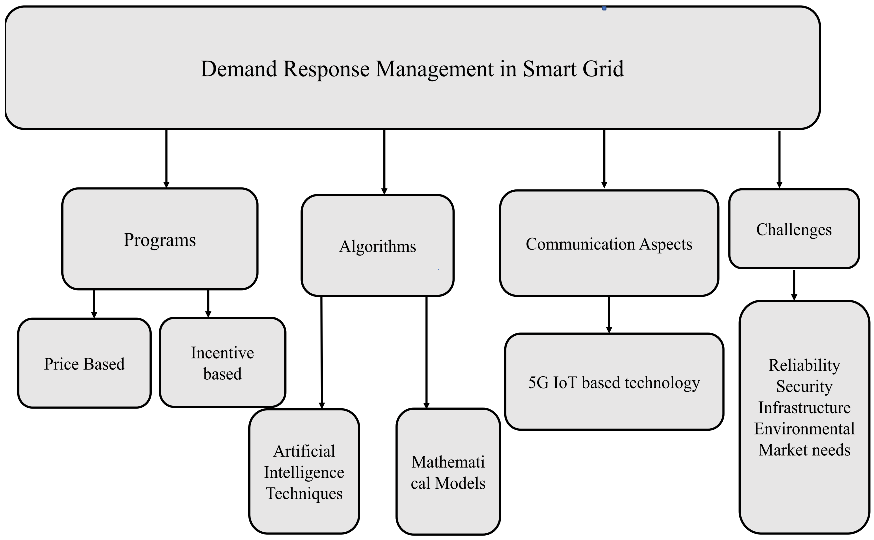

FIGURE 2. Road map architecture of the paper.

high priority, with fog edge-based servers deployed in close proximity to home area networks (HANs) for preprocessing and analyzing information collected from smart IoT devices. Moreover [9] investigated 5G wireless networks for the SGs. This work justified the need for 5G technology in a SG and the areas where the new power grid can benefit the access of data. The main aim of this work was to demonstrate 5G architecture in general compared to other wireless technologies and new networks in SGs, thus bringing the Internet of Energy into the future.

Considering the algorithms [20] provided a review of AI techniques for distributed SG. In this paper, AI algorithms, objectives, and their limitations are reviewed. Reference [21], reviewed AI-based load demand forecast techniques for buildings and SG. This paper gave a systematic literature review of AI-based short term load forecasting techniques. In [22] authors provided a comprehensive review of IoT applications in SG. Although all these papers conducted a review from a different angle, none of them combines all these aspects with a broad vision of the challenges facing the implementation and advancement of DRM.

C. ARTICLE STRUCTURE

In this paper a wide spectrum of models, algorithms, and applications of DRM programmes in residential areas with an emphasize on 5G telecommunication are first investigated. Then, DRM programmes in smart generation, transmission, distribution, and end-users are studied. A discussion about the SG challenges is thereby provided. Given the importance of 5G telecommunication potential applications of 5G IoT in SG with emphasis on available technologies is also provided. Finally, literature related to 5G telecommunication aspects of DRM in SG is reviewed.

The paper is organised as follows:

Section 2 will introduce fundamentals of DRM including the definition of DRM, DRM options, and a review on related parameters and communication aspects of DRM. Section 3 includes examples of models on DRM based on specific programs, including both incentive base and price-based options. Residential modelling applications that involve DRM enabled load model, home energy management systems and multi-agent systems are explained. Section 4 presents DRM algorithms. Section 5 consists of DRM applications in SG that involves current and ongoing programs in various parts of SG including generation/distribution, transmission, and substations. DRM benefits and challenges in SG are discussed in section 6, and finally, section 7 concludes the paper.

Table 1, represents the acronyms and their definitions.

II. FUNDAMENTALS OF DRM

A. DEFINITIONS OF DRM

DRM is a technology used to control energy demand during peak times to achieve a balance between the electricity supply and load. In this way, it can obtain better utilization of the available energy and lead to a more reliable system [23].

According to [24] the US Department of Energy classifies DRM as having two options: price-based and incentive-based. Price-based programs are defined based on the price signal which is sent to the end-users, and incentive-based programs are based on incentive or punishment that end-users may receive from the energy provider. These options are explained in detail in the next section. The price based options and direct load control which is one of incentive-based options are primarily offered technologies to residential users [4]. DRM is considered as the main feature of a SG as it provides optimized solutions by flattening the load curve as opposed to generating more energy to meet the peak demand.

DRM plays a crucial role in a smart environment as it can enhance the efficiency of the grid by leveraging the right programs. DRM programmes serves as interface between

TABLE 1. List of acronyms and corresponding definitions.

Acronyms	Definitions
5G	5th generation
DRM	Demand Response Management
SG	Smart Grid
DRAS	Demand response automation server
MAS	Multi agent system
SGG	Smart generation grid
SDG	Smart distribution grid
STG	Smart transmission grid
AI	Artificial intelligence
RTP	Real time pricing
CPP	Critical peak pricing
TOU	Time of use
DOE	Department of Energy
EV	Electrical vehicles
I/C	Interruptible/Curtailable (I/C)
CAP	Capacity market programme
DSO	Distribution system operation
TSO	Transmission system operator
AMI	Advanced meterring infrastructure
ISO	Independent system operators
BEMS	Building energy management systems
RTO	Regional transmission organizations
GLS	Group load shifting
DLC	Direct load control
MME	Mobility management entity
GGSN	Gateway GPRS service node

independent system operators (ISOs) / wholesale markets, transmission systems, distribution systems, and customers.

B. DRM OPTIONS

According to the existing literature [24], [25], DRM can be divided into two options:

- Price base options of DRM
  This category involves programs that are listed as: a) real-time pricing (RTP) in which unit price of electricity is periodically changed, b) critical-peak pricing (CPP) that changes normal peak price with a higher price to provide reliability for system and balance supply prices and c) time-of-use (TOU) tariffs which include different tariffs for different time intervals of a day or different seasons of a year and give customers time-varying rates that reflect the value and cost of electricity in different time periods. If the price difference between hours or time periods is significant, customers adjust the schedule of their flexible loads in order to take advantage of lower price periods. Consequently, from the utility's point of view, significant peak shaving can be achieved [3], [23].
- Incentive-base DRM
  According to the US Department of Energy (DoE) incentive-based demand response programs can be listed as direct load control (DLC), interruptible/curtailable service (I/C), demand bidding/buyback, capacity market programme (CAP), ancillary service markets (A/S).
  In general, incentive-based demand response can be considered as a programme that requests consumers to hand in the load control rights to utilities with some contracted limits and incentives [26]. This category requires more effort from the utility side to take into consideration the system reliability, economic dispatch, consumer comfort, and so on. As a type of mature incentive-based demand response, DLC has been thoroughly studied. These programs provide customers with load reduction incentives. The incentives might be separated from, or additional to, their retail electricity rate, which may be fixed (based on average costs) or time-varying. Load reductions are needed and requested either when the system reliability conditions are treated or when prices are too high [27].

C. RELATED PARAMETERS

For solving the DRM problems based on economic incentives or load-based incentives, various parameters have already been considered. These parameters include:

- Different time scales and stochastic reliability with consideration of renewable energy [28]
- Uncertainty in load, and the number of users [3], [28]
- Number of appliances and users [2], [4], [29]
- Networking aspects of DRM [5], [30]
- Production cost [23]
- Energy storage characteristics of appliances [31]
- Real-time congestion management in distributed networks [32]
- Operation duration of appliance [33]
- Effect of cooperation/competition of utilities [4]
- Outage cost [23], [30]
- Utility cost [30], [32]
- Costs paid for customer participation in demand response, and price elasticity [4]
- Market model (e.g. electricity or capacity marketing) [34]
- Customer behavioural characteristics [35]

These parameters can affect the performance and efficiency of the grid which are studied widely in literature. In the next section telecommunication aspects of DRM in the SG will be explained.

D. TELECOMMUNICATION ASPECTS OF DRM IN SG

Telecommunication is one of the most important advantages of SG, as it provides bidirectional flow of both information and electricity in the grid. In this way, many efforts have already been done to design an efficient communication network for DRM under the platform of SG [14]. The communication network in the SGs involves the following components:

- Data acquisition infrastructure which includes sensor networks, data loggers, gateways, modems, etc.
- An application server with database, calculation and analysis algorithms, alarming and reporting.
- User interfaces for visualization and configuration.

The above segments are considered for sending the communication signal in RTP or DLC programs. Typically, a signal broadcasts by the distribution or transmission system operator

(DSO/TSO). This signal might contain a price or a command for load shedding/shifting.

One modern system for automated DRM is Open ADR [36], [37] which is developed by the DRM research center at the Lawrence Berkley National Laboratory. Open ADR is a specification and an open-source reference implementation of a distributed, client server-oriented DRM infrastructure with a publisher-subscriber model. The components involve the following [37]:

- Demand Response Automation Server (DRAS)
- DRAS Client at the customers' sites.
- The Internet as communication infrastructure

The client usually is a communication library that is used by control manufacturers to make the product capable. Clients can subscribe to DR programs such as critical peak pricing or demand bidding, and the DRAS serves as a simple market platform and subscription manager. For instance, if a utility or system operator issues an emergency message to the DRAS, the server forwards the message to all clients that participate in the emergency programme.

E. MOTIVATION: IMPORTANCE OF INVESTIGATION ABOUT 5G BASED IoT FOR DRM

In recent years, with respect to progress in IoT and the advent of 5G technologies the infrastructure for DRM in SG is highly improved. DRM consists of programs that improve the efficiency of the SG by providing two-way interaction between different layers of the grid including generation, distribution, transmission, and consumption. The combination of 5G and DRM provides a network that is more secure, reliable, and faster. Such a network also consumes less power and can cover a massive number of connections. This is particularly needed for real-time DRM programmes where accuracy and speed are important factors. Because of the importance of DRM in SG, there is a large number of literature that studies DRM for the benefit of both consumers and energy providers [38]–[45]. However, to the best of our knowledge, none of these efforts have highlighted the potential application of 5G in DRM with a focus on algorithms and programs, whereas in this paper will address cover this issue.

F. 5G TECHNOLOGY FOR DRM

1) DEFINITION AND OUTLOOK OF 5G NETWORKS

The 5G networks stand for fifth-generation mobile technology and are superior over earlier versions of wireless communication technology. The new technology provides diverse abilities and encourages global networking and communication [7], [46], [47]. According to the Federal communications commission (FCC), the use-case of 60 GHz spectrum is allocated for this technology with the intention of providing very high service quality. Millimeter-wave communication, HetNets, massive multiple-input multiple-output (MIMO), and visual light communication are considered as emerging technologies alongside 5G [48].

According to [49], [50] the millimeter-wave communication utilizes underutilized mm-wave spectra ranging from 3 GHz to 300 GHz as the carrier frequency, and therefore provides very large bandwidth allocation in comparison with older generations. This technology consists of small base stations that provide sufficient improvement in network capacity, and coverage on a large scale.

Cloud assisted platforms with the stations provides the requirements of HetNets.

Massive MIMO technology is based on the application of spatial multiplexing for the utilization of extensive service antennas [51]. The new 5G technology related to visual light communication is called Li-Fi which benefits from low power, less interface, and very high spatial reuse.

There are different existing 5G architectures such as multi-tier architecture, cognitive radio network, device to device communication, and cloud-based architecture [52]. Each of the mentioned architectures has advantages and disadvantages which are summarised in table 2.

Figure 3, represents the road map of 5G in SG, and figure 4, represents application scenarios of 5G communication technology in SG.

TABLE 2. Advantages and disadvantages of different 5G architectures for DRM in SG.

Architecture	Advantages	Limitations
Multi-tier architecture	better and higher data rates with a considerable reduction of energy consumed	low reliability and comparatively very high operational cost
Cognitive Radio Network Architecture	minimum interference and improved network capacity	less energy efficiency and a major trade-off between the spatial frequency and the range of outage
Device to Device Communication Architecture	high data rate and instant communication with quick file sharing	Security
Cloud-based Architecture	resource sharing, reduction of cost with improved spectrum utilization	Security and privacy

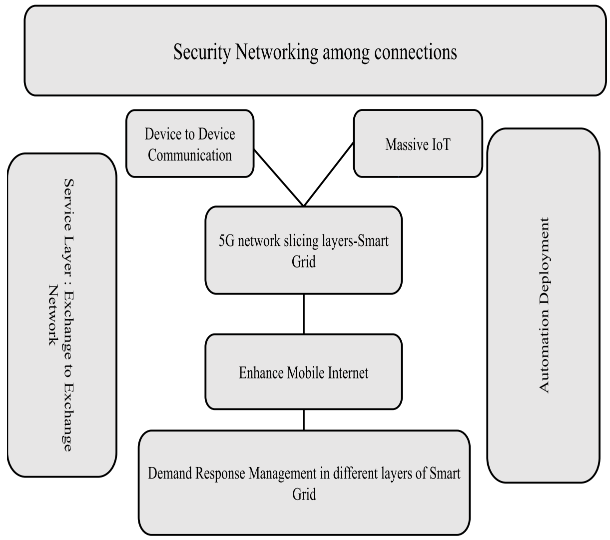

FIGURE 3. Road map architecture of 5G in SG.

2) APPLICATION POTENTIAL OF 5G IN SG

With respect to the advent of telecommunication technologies 5G is considered in a diverse range of projects around the globe. For instance, the VPP project in Finland, the neural grid project in the UK, the VirtuWind project in Europe, and the SG-eIoT project in China [6]. Some research has recently been conducted in order to make full use of 5G's advantages in smart grids. For instance recently a 5G network framework was designed to be used for the generic object oriented substation event in power systems [6]. This has been tested on the emulated 5G software Open5GCore. The results showed that 5G networks are able to transmit time-critical messages while satisfying a standard for power systems automation (IEC61850) [53]. In order to highlight advantages of 5G in comparison with previous generations, table 3 provides a comparison from 1G to 5G technologies [54].

TABLE 3. Comparison between 1G-5G.

Technology	1G	2/2.5G	3G	4G	5G
start deployment	1970-1984	1980-1999	1990-2002	2000-2010	2010-2015
Data Bandwidth	2 kbs	14.4-64 kbs	2 Mbs	200 Mbs to 1 Gbs for low mobility	1 Gbs and higher
Standards	AMPS	2G: TDMA, CDMA, GSM, 2.5G: GPRS, EDGE, 1xRTT	WCDMA, CDMA 2000	Single unified standard	Single unified standard
Technology	Analog cellular technology	Digital cellular technology	Broad bandwidth CDMA, IP technology	Unified IP and seamless combination of broadband LAN,WAN	Unified IP and seamless combination of broadband

Recently 5G is under deployment in many countries due to its great advantages over previous generations (1G - 4G) in transfer speed, reliability, security, power consumption, and number of connections. Therefore application of 5G for DRM programmes is more advantageous in comparison with previous 3G and 4G technologies. The advantages of 5G networks for DRM programmes in SG were investigated as bellow:

- Massive links of flexible loads for DRM [55]
- Fast transfer speed and low communication latency for remote control [56]
- Robust security and consumer privacy [57]
- High reliability and low power consumption [58], [59]

All mentioned factors provide a fast, reliable, highly secure technology for remote control for DRM in SGs. With respect to importance of deployment of 5G in SG, table 4 refers to some of the projects on DRM and communication networks with a focus on the application of 5G technology. Although, mmWaves is an important feature of 5G technology, however as mmWaves transmission distance is around 100 m which is not good to cover large distance areas, therefore a larger number of small cells should be deployed for a wider area. In this way ultra-dense cellular networks can be considered as one of the main features of this kind of networks. According to [6] the density of macro base stations per km^2 for 3G and 4G is 4-5 BS/km^2 and 8-10 BS/km^2 respectively. In contrast, for 5G this would be around 40-50 BS/ km^2.

3) 5G TECHNOLOGY FUTURE OPPORTUNITIES

The advantages of 5G technology in the future SG are provided as follows:

- Providing fast, reliable, and integrated bidirectional communication networks that can handle voltage and frequency fluctuation effect of additional renewable energy sources in advanced SGs [66].
- Preparing ubiquitous data acquisition and visualization from various layers of SG with the bringing forth of a massive AMI [67].
- Having real-time computing with the capability of sending time-critical messages as explained in [68]–[70].
- Providing an automated distribution network [70].
- Supplying edge computing and efficient load management [71].
- Increasing network security and privacy [72].

Figure 4 illustrates an example architecture for 5G cellular network. According to [73], recently, a combination of several cellular technologies along with techno-economic trends have emerged. This will bring the debate to LTE-A-based Fifth-Generation (5G) mobile wireless technology as the global future grid communication networking standard. In this research 5G cellular technologies for supporting future power grid communication networks was explained. Cellular LTE-A-enabled machine-to machine (M2M), machine-type communications (MTC), and LTE/LTE-A have been already selected by US and EU federal authorities to be the technology for future public safety mobile broadband networks [73]. In [74] 5G as an enabler for secure IoT in the SG was introduced. Moreover, [75] studied the role of Joint 5G-IoT framework for SG interoperability enhancement.

G. RESIDENTIAL DEMAND RESPONSE

In this section, we will investigate the simulation and modelling applications of residential demand response including enabled load models, home energy management systems, and multi-agent systems (MAS).

Demand response in residential areas is a recent effort to improve the efficiency of the electricity market and the stability of the power system. Simulation and modelling are a way to identify and quantify the impacts and benefits of DRM applications with aim of reducing electricity peak demand and match the demand with supply including the renewable generation. In this regard, the development of applicable residential load model and efficient home energy management systems are critical issues to allow incorporation of dynamics in use patterns.

TABLE 4. Projects related to application of 5G for DRM.

Project	Country/ Region	Objective	Advantage	Paper/Report	Year
Second generation advanced metering system	The State Grid Corporation of China, Enel in Italy, and Noth America	Current infrastructure for powerline and radio frequency mesh technology will be shifted to 5G technology	Higher reliability, security, less power consumption	[60]	2019
WIreless for VErtical (WAVE)	5G Test Network in Finland , Co-funded by the Finnish Funding Agency for Innovation (Tekes), Telephone Company and Mobile Network Operator in Sweden	Using 5G to improve business value of SG and develop concepts and enable technologies, as well as to test and experiment new services offered by 5G	To serve sectors like smart grids and remotely controlled machines by providing ultra reliable low latency communication (URLLC) and also massive machine type connectivity (MTC)	[61]	2019
Updating the SG to Nueral Grid by providing ubiquitous connectivity in power system using 5G technology	United Kingdom	5G connected smart city	Households will save up to £450 a year on bills, Advantages in healthcare (telehealth and fast data transfer), Transport (reducing the road traffic congestion), to deal with increasing demands more efficiently	[62]	2018
VirtuWind	Europe, This research received funding from the European Union's Horizon 2020 research and innovation programme	Development and demonstration of a software defined network (SDN) and network function virtualisation (NFV) ecosystem in real wind parks	Improvement of Quality of Service (QoS), Lower operational cost	[63]	2015-2018
State Grid electric Internet of Things (SG-eIoT)	China	Acceleration of the construction of smart home and smart cities	Dealing with increased demand due to large number of devices connected to Internet by 2030 and providing IoT infrastructure to cover users' demand	[64]	2019
China's Largest 5G SG	Qingdao Branch of China Telecom, Huawei, and the Qingdao Power Supply Company of the State Grid Corporation of China (SGCC)	Development of an end to end dedicated 5G secure network, based on network slicing and mobile edge computing (MEC)	Ultra low latency network for applications such as intelligent power distribution, monitoring on substation operations and service status, peak load shaving at base stations	[65]	2020

In the residential sector, the DRM enabled technologies usually relate to smart home, which features an energy management system (EMS) that intelligently controls household loads with the association of smart meters, smart appliances, plug-in hybrid electric vehicles (PHEVs), home power generation, and storage equipment.

In a domestic dwelling smart meters can provide information for both utilities and consumers such as home load profiles and dynamic price signals. So, a home EMS allows customers to conveniently manage this information. The flexible demand aspect of DRM application enables time-shift electricity consumption by bringing forward or delaying the use of appliances. For instance, EMS monitors real-time loads and price signals and optimizes electricity consumption by switching on/off appliances without influencing costumers' comfort. Figure 5 depicts a smart home with various

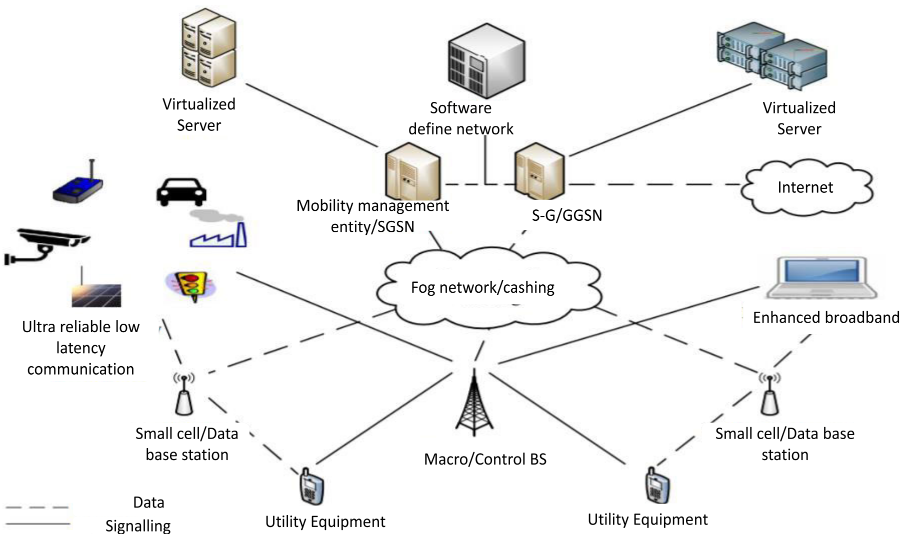

FIGURE 4. **An example architecture for 5G cellular network [76].**

functions performed intelligently by EMS [77]. In [78] a survey for EMS in SG was provided. This paper classified EMS behind the meter into three categories in terms of technology, economic, and social layers. Moreover, an overview of the enabling technologies and standards for communication, sensing, and monitoring purposes was also presented. An application of IoT in load control was considered in [79], where load shedding and smart direct load control were provided using Internet of Things (IoT) to minimize the power outage in sudden grid load changes.

1) HOME ENERGY MANAGEMENT SYSTEM

Using a home EMS, load can be controlled either by a utility or by the household. The former one is DLC where the utility directly controls the load in peak demand period and the latter is defined as indirect LC.

In the DLC option, the utility directly controls consumers' electrical equipment by sending a signal to the home EMS.

In indirect LC, consumers configure the home EMS to control the equipment. The configuration includes comfort levels, maximum consumption, maximum demand limit, etc.

Various optimization algorithms are available to assist customers to schedule their electrical equipment according to information received from a utility such as price-based signals or curtailment base signals. The HEMS enables scheduling equipment by switching on/off selected household loads or by managing the home generation and storage equipment, to reach an optimized objective in electric bills and customer comfort. In [77] HEMS's concepts, configurations, and technologies were reviewed. To understand the concept of HEMS, figure 5 illustrates the overall architecture of the system.

2) MULTIPLE AUTONOMOUS SYSTEM

A MAS generally refers to a body of multiple autonomous agents that interact, cooperate, and negotiate with each other in order to achieve a common goal. In MAS related to SG

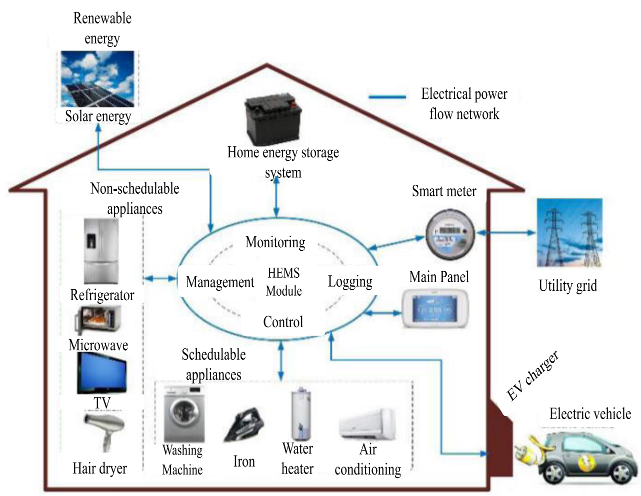

FIGURE 5. **Overall architecture of HEMS [77].**

and especially smart homes, DRM components can be captured by various types of agents such as generator agents, home agents, and transmission and distribution agents. If the concept of a micro-grid is involved this architecture can also be considered as a MAS where several components interact through this structure. Through the interaction of micro-grids and /or agents several interesting insights can be developed. It is argued that smart homes may no longer be modelled by passive load curves but should be considered as active participants that not only consume electricity but also generate and store it. Also, a MAS is proposed for modelling homes as autonomous agents that make decisions to buy, sell, or store electricity based on their present and expected future loads, generation capabilities, and storage capacity. There are literature related to application of MAS in SG for improved system operations, performance and interaction of different parts of the SG as have been discussed in [80]–[83].

III. DRM APPLICATIONS IN SG

A. DRM IN SMART GENERATION/DISTRIBUTION GRID (SGG/SDG)

In recent years several developments that have led to the expansion of SG's new face of electricity management appeared which involve concepts such as environmental protection which includes renewable generation and DRM for better asset utilization including preservation of reliability, as well as enhanced customer's choice are considered as key drivers for development of SG. Also, bidirectional interaction among wholesale markets/transmission operations and retail markets/distribution operations is an important point that should be taken into consideration, especially with the progress in IoT systems and possibility of cyber security attacks. Moreover, the reduction of the power consumption by consumers via initiating on-site power generations like [48] brings new potentials for DRM programmes. For instance, the UK's recent initiative "Prospering from the Energy Revolution" to promote smart local energy systems, has highlighted the importance of study in this area [84], [85].

Thus, investigation about the role of DRM or distributed energy resources (DER) under the platform of SG is crucial. Especially, in the context of energy and ancillary service markets facilitated by the independent system operators (ISOs)/regional transmission organizations (RTOs), the market products are dependent on the ISO/RTO design and applicable operational standards.

The emerging use of thermal storage for peak shifting, the anticipated growth and cost reduction of solar photovoltaic (PV) generation at residential and municipal levels, the anticipated shift from conventional fuel transportation to plug-in electric vehicles (PEVs), the advent of low-cost smart sensors, and availability of two ways communication network across utility service territory are anticipated in future SGG/SDG system operations. It should be noted that all of these programs require DRM to control and optimize the energy consumption to not only protect the grid from outages and prevent from experience such as California's energy crisis which caused to turn off in the large extent, but also provide the opportunity for better consumption of electricity especially in peak demand periods. In this way [86] provides a comprehensive survey on consumers' empowerment, communication technologies, and renewable generation in the SG to address the issues and challenges about the aforementioned key concepts.

B. DRM IN SMART TRANSMISSION GRID (STG)

The power transmission grid (PTG) has been developed in recent years progressively [87]. There are many challenges related to the concept of STG that can be attributed to environmental and customer needs, infrastructure challenges, and innovative technologies. On the perspective of SG, there are some programs that were created to achieve tremendous gains in the enhancements of system reliability, and capacity. For example, the IntelliGrid program is initiated by the electric power research institution (EPRI) with the aim of creating a technical foundation for the smart power grid which links electricity with communications and computer control. It provided the methodologies, tools, and recommendations for open standards and technologies with implementation of advanced metering, distribution and automation, demand response, and wide-area measurement [88]. There are also other programs such as SmartGrid, formed by the European technology platform (ETP), or Federal Smart Grid Task Force which was established by the US, with objectives that were identified for providing electricity networks flexible to customer's requests, access to network users and renewable power resources, reliable for security and quality of power supply and economic to provide the best value and energy management.

In all these programmes DRM is considered as one of the important ingredients of SG. The transmission grid consists of three interactive parts: control centers, transmission networks, and substations. Under the platform of SG, smart control centers involve monitoring/visualization, analytical capability, intervention, and interaction with the electricity market. Then, smart transmission networks consider high efficiency, flexibility, self-healing, advanced transmission facility. Finally, smart substations are related to DRM programmes that deal with aspects such as real-time modelling, and data management.

C. DRM IN SMART SUBSTATIONS

The smart substations in the transmission grid are to enable more reliable and efficient monitoring, operation, control, protection, and maintenance of equipment in substations. The major characteristics of a smart substation include digitalization, autonomy, coordination, and self-healing. Smart substations should provide advanced power electronics and control interfaces for renewable energy and demand response resources. These systems incorporate micrograids to deliver quality power to consumers. There are studies around micro-grids and DRM in SG which emphasizes the importance of DRM especially in STG. For instance [89] applied demand response with an artificial neural network-based model for predictive control in SG. It can be deduced that with the cooperation of DRM and STG, increased flexibility in control, operation and expansion will be provided. Considering the main goal of smart substations in SGs it should be noted that development and implementation of any proposed integration framework requires a concerted effort for extension of the existing technologies in the future. This should focus on promoting forward-looking research and development to solve underlying critical issues in the long term in order to ensure economic prosperity and guarantee the environmental health.

D. SMART CONSUMERS

Regarding the recent development in Building Energy Management Systems (BEMS) which have followed the advancements made in electric loads monitoring in residential buildings, the front-end topology of typical loads has been changed and diversified. So, understanding the working state of these loads, using power consumption monitoring techniques is an important issue especially, for DRM programmes. This would enable customers to control their energy consumptions in peak demands. The concept of smart consumers refers to those groups of residential electricity consumers that use load monitoring technologies to be aware of price changes in the price in critical peak periods and control their consumption accordingly. Based on this definition, the more advanced monitoring technology, the smarter the consumer is. The usage behavior is a crucial part of load monitoring and a practical product of load monitoring should provide energy usage information in the residential building. Usage behavior is related to two factors: consumer consumption behavior and load diversity.

- Consumer energy consumption behavior
  This involves factors such as the size (large, medium and small), sector (residential, industrial, commercial and agricultural), income level (high, middle and low) and finally social or cultural level (high, average and low) of the consumer.
- Load behavioral aspects of appliances
  In HEMSs it is important to consider the load diversity as it plays an important role in DRM regarding modeling, scheduling, and optimization. Load behavior is related to power consumption, application of appliance, and time period that the appliance should be on. Also, it is an important factor in load monitoring. For example, loads with really small power consumption, like cell-phone chargers, hard drive adapters, transformer adapters do not need to be monitored. Even though these loads account for a large amount of waste energy, they are still too small to be considered in DRM in practices of home energy management.

IV. DRM MODELS AND ALGORITHMS

To address the DRM problems regarding the choices between economic and load incentives, various algorithms have already been proposed with different objectives. For instance, dynamic programming [90] or fuzzy logic and linear programming that have also been proposed in [91] are mostly used for load management programs. References [92], [93] developed load controlling algorithms. It is important to know which type of load is controlled. If it is a thermostatically driven load, it should be clarified whether it is air conditioners, space heaters, water heaters or water-pumping loads. In load management programs the next step after load identification is solving the problems related to the kind of identified loads. For instance to solve cold load pick-up problems for thermostatically controlled appliances (TCA) [94]. For solving load management problems various parameters have been practiced. In this paper some parameters that have already been practiced were mentioned, however, this is an open issue, and in the future other parameters may be discovered as well. Also, there are many programs under which load management in DRM is concerned. Some of these programs are: unit commitment programs [95], [96] which involves subprograms like centralization/decentralization or resource prioritization [97]. On the other side, there are some algorithms that have been proposed for price based scheme of DRM and are heavily dependent on the kind of programme under practice, e.g. RTP, CPP, and TOU. In this regard, there are many studies on load management techniques [2], [4], [29], [98], [99]. Another approach is the game-theoretic approach which is a common method for the problem of welfare maximization when two sides of companies and consumers compete with each other to gain maximum benefit [100].

The models and algorithms that are used for solving DRM problems are divided into two categories. These categories consist of convex optimization and machine learning techniques. These approaches might be selected based on the kind of the problem and available parameters that are taken into consideration. In the following sections an example for each approach is considered.

A. ALGORITHMS BASED ON CONVEX OPTIMIZATION

In this section an example for solving a DRM problem based on convex optimization approach is explained to determine the local optimum in an optimization problem. In this scenario their is a bidirectional interaction between end-users and energy providers.

In [4], RTP was formulated as maximization of social benefits among the consumers and the energy provider. It is defined based on the subscription of aggregation of users' utility from energy provider's cost function. The constraint is the summation of the power consumption not exceeding the generating capacity at each time interval. As maximization of users' satisfaction and minimization of the cost imposed to energy provider is the goal, therefore, mathematically the optimization problem can be written as:

$$\underset{x_i^k \in I_i^k,\ L_k^{min} \leq L_k \leq L_k^{max}\ k \in K, i \in \{N\}}{\text{maximize}} \sum_{i \in \{N\}} U(x_i^k, w_i^k) - C_k(L_k)$$
$$\text{subject to} \sum_{i \in \{N\}} x_i^k \leq L_k, \forall k \in K \tag{1}$$

In above equation function U is the utility function that shows the level of satisfaction of consumers. It is defined as a function depending on factor x and w which are considered as consumption and a factor which represents level of consumption for each user respectively. The $\{K\}$ is denoted as a set of k timeslots. Here, x_i^k is the consumed power at time interval k of consumer i. It is assumed that there are a set of N users requiring electricity and each consumer $i \in \{N\}$ requires some electricity to run the appliances. The power consumption for each time interval is bounded as $x_i^k \in [m_i^k, M_i^k]$, where m_i^k is a minimum power consumption, and M_i^k refers to maximum power consumption. The cost function of providing electricity is assumed to be increasing and strictly convex as:

$$C_K(L_k) = a_k L_k^2 + b_k L_k + c_k, \quad a_k, b_k, c_k \leq 0 \tag{2}$$

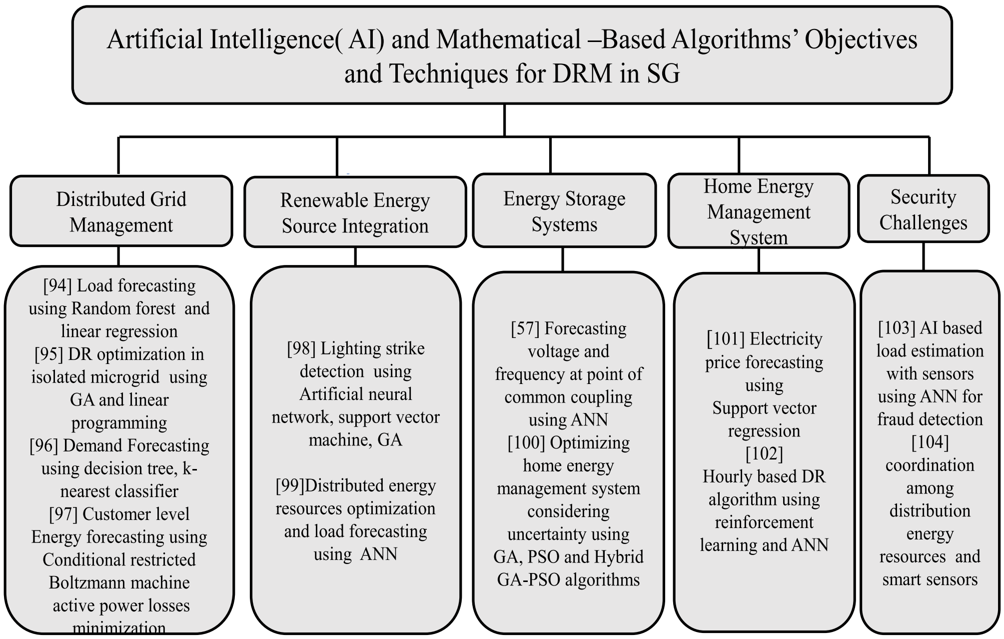

FIGURE 6. **AI based algorithms for DRM in SG [67], [101]–[111].**

The problem can be solved separately at each time interval by users and also the energy provider. In this case, each user determines the optimal consumption x_i^{k*} from

$$x_i^{k*} = \underset{x_i^k \in I_i^k}{\arg\max} U(x_i^k, w_i^k) - \lambda^k(x_i^k) \tag{3}$$

where λ^k is the Lagrange multiplier representing the energy price. Then x_i^{k*} is sent to the energy provider who determines the optimal L_k from

$$L_k^* = \underset{L_k^{min} \le L_k \le L_k^{max}}{\arg\max} \lambda_k(L_k) - C_k(L_k) \tag{4}$$

The energy provider updates the price λ_k according to the gradient projection method that is explained in [4] with consideration of load uncertainty and variation in the number of users. We consider this approach as mathematical solution for solving an optimization problem which gives a local minimum. However, there are some problems that finding the local minimum is difficult or not possible, therefore machine learning approaches can be considered. Such kind of problem and an algorithm for solving it, is explained in the next section.

B. A REVIEW ON ARTIFICIAL INTELLIGENCE TECHNIQUES FOR DISTRIBUTED 5G ENABLED SMART GRIDS

In this section AI techniques that are used for various DRM programmes are reviewed. The main goal of this section is to provide an understanding of AI algorithms and methods that improve the performance of SG. Figure 6, provides a literature review on AI-based algorithms for various problems such as load forecasting, price forecasting, lightning strike detection, and so on. This figure illustrates how AI algorithms are used in various parts of a SG. These include distributed grid management, renewable energy source integration, energy storage systems, home energy management systems, and security aspects for fraud detection. As the SG will be more reliable and the communications in different layers will be faster and more secure under the platform of 5G, in this section we also investigate the AI algorithms which improve computation offloading in 5G systems. As edge computing in 5G networks are quite prevalent to improve performance of SG, therefore we provide a review on AI techniques in computation offloading edge computing and, in vehicular edge computing network.

Table 5 provides research into available algorithms and their advantages in computational offloading in edge computing for 5G systems.

C. ALGORITHMS BASED ON ARTIFICIAL INTELLIGENCE APPROACHES

In this section we provide an example for application of reinforcement learning and artificial neural network for demand response in home energy management system. The demand response algorithm was executed in [109] and is represented in figure 7. A steady price prediction model based on artificial neural network is explained to predict future electricity price. In this algorithm multi-agent reinforcement learning was adopted to make optimal decisions for different home appliances. In this work each residential appliance has its own agent with different actions. They can make the decision for turning an appliance 'on' or 'off' based on some rewards or incentive mechanisms. In this scenario the loads are divided into non-shiftable load that has only one action, "on", as it cannot be scheduled; shiftable load that has two available

TABLE 5. Review on AI algorithms for Edge computing in 5G networks.

Algorithm	Objective	Technique	Advantage	Paper	Year
Neural networks and deep learning algorithms	1.Minimizing offloading overheads,2.Addressing the difficulties of determining the best node to receive the offload computation in an eadge environment	1. Deep supervised learning in mobile edge computing devices,2.Deep learning to select a node with shortest response time	1.Reducing system cost,2. High accuracy in response time prediction	[112], [113]	2017,2019
Regression algorithm	1.Development of intelligent code offloading decision making system	1. Using a nonlinear optimization solution	1.High accuracy in offloading prediction	[114]	2016
k-Nearest Neighbors, Decision tree and Naive Bayes	Solving the problem of underachievement in imprecise decisions	Providing two different evaluations based on best two performing algorithms and shifting context information between experiments	achievement of 95 percent offloading decision accuracy	[115]	2019
Deep reinforcement learning	To access an excellent resource allocation of communication and computing for vehicular networks	Exploration of vehicle's mobility	Enhanced gains in cost efficiency	[116]	2018
Deep Q-learning, Markov decision process, and reinforcement learning	Automatic management of offloading requests	Decision making based on network status and resource demand for latency minimization using Markov decision process and reinforcement learning. The evaluation of the model is based on the N-queen problem regarding response time and energy consumption analysis	Improvement in response time and energy consumption	[117]	2019
Multiple-Kernel Clustering (MKC) algorithms	Intrusion detection approache for 5G and IoT networks	Improvement of Intrusion Detection Systems (IDSs) by providing an approach to distinguish between trafic attributes and attack behaviors for 5G and IoT networks	Solving problem of attribute missing in sample data for intrusion detection	[118]	2021

actions, "on" and "off"; and finally controllable load that has set of actions, i.e., 1, 2, 3…, to represent various power ratings at different levels. Also, the states are denoted by appliance's energy consumption information. The key elements in this RL include: a discrete hour h, an action a_h, a state s_h, and a reward $r(s_h, a_h)$. The term ν is used to denote the policy mapping states to actions, i.e., $\nu : a_h = \nu(s_h)$. The objective of this problem is to discover an optimal policy ν for each state s_h so that the action a_h selected maximizes the reward using Q-learning technique by solving the following equation:

$$\nu^* = \arg\max Q(s_h, a_h) \tag{5}$$

V. DRM BENEFITS AND CHALLENGES

A. DRM BENEFITS

According to the US DoE report on demand response benefits analysis, the most important benefit of demand response is improved resource-efficiency of electricity production due to closer alignment between customers' electricity price and the value they put on the electricity. This efficiency creates a variety of benefits, which can be listed into four groups:

a) Participant financial benefits that includes bill savings and earned incentive payments.

b) Market-wide financial benefits consisting of production costs and prices down for all wholesale electricity purchasers due to the use of the most cost-effective generation; reduced the costs of power supply in the long term and eventually passing some of the benefits to the consumer bill savings.

c) Reliability benefits that involves reducing costs and inconvenience for consumers as a result of the improvement of system security and adequacy.

B. DRM CHALLENGES

Based on the previous review of existing research and practices, a variety of challenges and opportunities for DRM programs have been identified below including those that haven't been done much in the scientific community. The main challenge remains on increasing the efficiency of the SG.

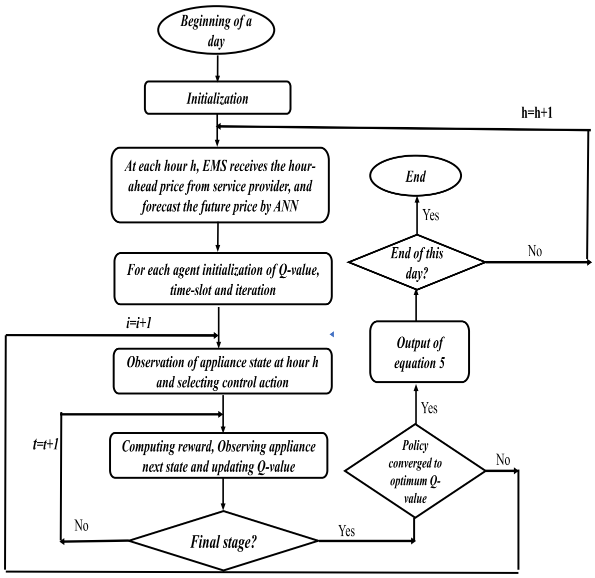

FIGURE 7. Flowchart for implementing the algorithm proposed in [109].

- Modelling
  There are many DRM challenges regarding the selected parameters that can be used for modeling in DRM programs. For instance, one aspect of modeling the appliances is to see whether it operates on a discrete power level or a continuous range of power levels. Considering the fact that some appliances that can be modelled as a kind of rely upon a continuous range of power levels may work on discrete power levels for a short period of time which can cause new approaches for modelling loads in DLC programs. Such models are not only applicable for non-consistent behaviors of loads but also are applicable for price-based programs as well [119], [120].
- Security Challenges
  There are many programs under SG which involve interaction among several utilities or agents such as MAS [51], [121], group load shifting (GLS) [122], or micro-grids, where exchange of power usage information is needed. Therefore security issues are an important challenge that needs to be taken into consideration. In this way there are a wide range of literature that considered security challenges in IoT based SG [123], [124]. Some of security challenges in IoT based SG consists of standardization protocols, cognitive capability, power, consumer illiteracy, weak regulations, privacy issues, and so on. While 5G networks provide higher bandwidths and lower latency for edge IoT devices to access the core network, it has also the potential to expand the attack surface of the core network. Therefore there are some ongoing research to improve the intrusion detection systems using machine learning such as [118] which has applied multiple-kernel clustering (MKC) algorithms to prevent external intrusions. However, processing massive amounts of data is a challenge that still needs more focus in future works.
- Reliability
  Reliability is one of the most important aspects of DRM programs in SG. In [125] reliability issues of SG neighborhood area networks (NANs) were discussed. According to this research communication reliability for nodes and links consists of aspects such as reliable networking design, node and link failures, system malfunction related to failures in computing systems, power outages related to loss of electricity supply in a certain period, and cyber attacks are considered as one of the biggest issues to system reliability.
- Market/Customer needs
  Power market policies and DRM programs need to be developed to sustain the transparency and liberty of the competitive market. Customer satisfaction with electricity consumption should be enhanced by providing high quality/price ratio electricity and customers' freedom to interact with the grid. In order to address this challenge [126] introduced a smart algorithm to maximize the benefit of both end users and energy providers.
- Infrastructure challenges
  The existing infrastructure for electricity transmission has quickly aging components. Also, with the pressure of increasing demands, network congestion is increasing. Therefore, fast online transmission tools, wide-area monitoring, measurement and control, and fast and accurate protections are needed to improve the reliability of the network. Also in modern SG because of enhancement in IoT systems the security issues should be considered seriously. In this way SG infrastructure should be reliable enough to analyse big data in a short period of time. One of important factors related to network infrastructure in SG is resilience, which is a property of systems that describes their ability to be recovered from catastrophic events. In [127] the methods, challenges and opportunities related to SG resilience were discussed. Elements making up the system, their configurations and interactions and the environment that surrounds the system are three key factors that influence the resilience of the infrastructure of the SG.
- Innovative technologies
  Related to innovative technologies there are two key points that should be considered. On the one hand, the innovative technologies, including new materials, advanced power electronics, and communication technologies, are not yet mature or commercially available for the revolution of SG. On the other hand, the existing grids lack enough compatibility to accommodate the implementation of modern technologies in the practical networks. As DRM programs are highly related to aspects such as automation especially for RTP programs, innovative technologies should be taken into consideration. There are challenges related to 5G IoT based SG that are mostly relevant to security and reliability of the system. In this regard [9] discussed challenges related to 5G IoT based SG networks. For instance, the emergence

of the 5G network will lead to a significant increase in the number of connected devices. This will lead to a rise in the power consumption that should be considered for further investigation.

- Economic challenges
  The gap between lagging investment and increasing power demand causes deterioration in power reliability, which is an economic challenge. Therefore, for a successful DRM programme a suitable tariff and enabled technology is required. In this regard there is a wide range of literature providing solutions to optimize benefit of different parties in SG [4].
- Other Challenges
  There are also other challenges such as lack of a direct connection between increasing presence of renewable energy sources, measurement and verification, lack of interoperability and open standards, and finally lack of customer awareness and education.

VI. CONCLUSION

This paper has provided a review of DRM programmes, models, algorithms, communication aspects, and applications as well as its benefits and challenges under the context of SG, considering the potential application of 5G technology. Both the price-based options and incentive-based options were investigated.

Regarding the fact that SG consists of four parts of generation, transmission, distribution, and end-users, current and ongoing DRM programmes were reviewed in each part of the grid separately. However, there are multi-dimensional challenges related to the implementation of SG programs, including economic, environmental, infrastructural, innovative, and marketing concerns. In this paper DRM as a useful tool that can be considered to overcome these challenges in its ongoing and future programs was investigated and the benefits that can be achieved through advanced DRM programmes were explained. This paper presented an overview of various aspects of DRM with the goal of providing a vision for future research. Applications beyond 5G in SG and improved AI algorithms to provide a facility for very low-latency communications are promising areas for future investigation.

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SAHAR AHMADZADEH received the Ph.D. degree in electronic systems engineering from the University of Essex, in December 2017. During her Ph.D. degree, she gained experience for getting involved in a number of EPSRC funded projects in the Department of Computer Science and Electronic Engineering (CSEE), as a Research Officer, a Research Assistant, and a Research Admin. She was a Graduate Laboratory and Teaching Assistant with the Department of CSEE and Mathematics Science, University of Essex. She was also with the Advanced VLSI Laboratory, University of Tehran, Iran, as a Postdoctoral Researcher. She joined an integrated project between the University of Bolton and a Healthcare Company located in Chester, as a Wireless Sensor Development Engineer. She is also collaborating in writing EPSRC research proposals. She is currently a Senior Research Associate (SRA) with the School of Computing Science, University of East Anglia (UEA), U.K. Besides doing research, she is also teaching introductory programming to foundation year students at UEA. She has experience getting involved in various projects related to wireless networks and electronics in the Universities of Bolton, Essex, and UEA. Her research interests include wireless sensor networks, the IoT, optimization, AI, wearable electronics, smart grid, and energy harvesting. Her current research is going under the supervision of her Smart Emerging Technologies Laboratory. The areas of relevance concern the Internet of Things, edge and cloud computing, network management, and UAV protocols for search and rescue and disaster communications. She achieved the National Elites Foundation Award and the Innovate U.K. Award. She is a Reviewer of various journals, such as IEEE ACCESS, *International Journal of Communication Systems*, and *Wireless Networks*.

GERARD PARR is currently pursuing the Ph.D. degree in self-stabilising protocols from Ulster University (aspects of which were completed with UCL). He is also the Full Chair in telecommunications engineering and the Head of the School of Computing Sciences, University of East Anglia. He is one of the Founding Fathers of the Internet (Professor Jon Postel), as a Visiting Research Scientist at the DARPA/the University of Southern California Information Sciences Institute, Marina Del Rey, Los Angeles. Within his academic career, areas of research include wireless sensor clouds, disaster response communications, big data event management, ICT for the rural economy, delay-sensitive protocols, and energy-aware autonomic networking, and the IoT-edge computing. He is an Invited Member of the EPSRC Peer Review College. His academic research collaborations include MIT, the Georgia Institute of Technology, The University of Arizona, UC Berkeley, UC San Diego, USC-ISI Los Angeles, the University of Florida, University College London, Southampton, Surrey, QMUL, Oxford, St Andrews, Exeter, Lincoln, Lancaster and Cambridge, the Beijing University of Posts and Telecommunications (BUPT), Tsinghua University, Peking University, and the Indian Institutes of Technology in Mumbai, Madras, Kanpur, Hyderabad, Delhi, Mandi, and IISc Bangalore. He was previously appointed as a Senior Guest Editor for prestigious IEEE JOURNAL ON SELECTED AREAS OF COMMUNICATIONS (JSAC) for a Special Issue on Communications Challenges and Dynamics in UAVs.

WANQING ZHAO (Member, IEEE) received the Ph.D. degree from the Intelligent Systems and Control Group, Queen's University Belfast, Belfast, U.K., in 2012. He has previously held several academic and research positions at Manchester Metropolitan University, from 2019 to 2020, Cardiff University, from 2014 to 2018, and Loughborough University, from 2013 to 2014. He is currently a Lecturer with the School of Computing Sciences, University of East Anglia, Norwich, U.K. His work has focused on the development of low-complexity machine learning, optimization, and control algorithms, and their applications in energy and water management, smart city, and industry 4.0. Much of his research has appeared in prestigious journals, such as IEEE TRANSACTIONS ON CYBERNETICS, IEEE TRANSACTIONS ON FUZZY SYSTEMS, IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS (SMC), and *Proceedings of the Royal Society*.