IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 13 December 2022, accepted 23 January 2023, date of publication 25 January 2023, date of current version 1 February 2023.

*Digital Object Identifier 10.1109/ACCESS.2023.3239834*

SURVEY

# A Survey of Cyber-Physical Systems From a Game-Theoretic Perspective

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This work was supported in part by The University of Queensland Solar (UQ Solar), in part by the U.S. National Science Foundation under Grant ECCS-2039716, and in part by the C3.ai Digital Transformation Institute.

**ABSTRACT** With the emergence of the Internet-of-Things (IoT), artificial intelligence, and communication technologies, cyber-physical systems (CPS) have revolutionized the engineering paradigm with profound applications in many aspects of society including homes, energy, agriculture, health-care, transportation, business, and manufacturing. A CPS uses suitable computational techniques such as game theory to enable different entities to interact with one another for taking necessary actions to obtain selected objectives. Recent literature on CPS has extensively used game theory to approach a variety of technical challenges. In order to make these contributions more accessible to a broader audience, there is a need for studies that can provide readers with a comprehensive understanding of different types of CPS and their attributes, then clearly outline why game theory is relevant for modeling different aspects of CPS, and also discuss how game theory has been used in relevant literature to date. This paper bridges this gap by 1) providing a general discussion of different types of CPS and their characteristics; 2) giving an overview of different types of game-theoretic approaches; 3) explaining why game theory is appropriate for modeling different types of CPS; and 4) finally, studying how game theory has been used in different CPS types to address their challenges. Further, we also identify some key research challenges for future investigation where game theory could be applied as a potential solution.

**INDEX TERMS** Cyber-physical system, game theory, smart grid, electric vehicle, transportation, medical, industry 4.0, unmanned aerial vehicle, survey, review.

## I. INTRODUCTION

Cyber-physical systems (CPS) represent an emerging generation of engineered systems that are built from, and depend upon, seamlessly integrated computing, communication, and control technologies [1]. The first notion of CPS takes us back to 1941 when, soon after the invention of Z3, the first fully functional program-controlled computation machine was developed by Konrad Zuse for the survey of aircraft wings [2]. Later, in the 1990s, with the technological advances in sensors, instrumentation, networking, and embedded computing, much greater interest in enabling interactions between computational and physical systems began to emerge [1]. Around 2006, "cyber-physical systems" found its formal name at the National Science Foundation in the United States [3].

The widespread exploration of CPS is motivating customer-focused and intelligent solutions in many industries: from home automation [4], smart city [5], and energy management [6] to health services [7], transportation [8],

The associate editor coordinating the review of this manuscript and approving it for publication was Luca Bedogni.

  

agriculture [9], and entertainment [10]. Disruptive innovations have been possible in CPS due to their ability to enable interactions between different components within systems [11] with one another through digital platforms, e.g., blockchain [12], to make well-informed, real-time, and intelligent decisions in the physical world. This can be demonstrated via two simple examples: (i) In the energy sector, energy users with distributed energy resources - such as rooftop solar panels and batteries - can interact with one another in the virtual layer (digital platform) of a smart grid to decide on various energy trading parameters and exchange electricity with one another for the negotiated price over the distribution network (physical system) [13]. (ii) Similarly, in the transportation system, vehicles can interact with one another and with road-side intelligent nodes through a digital platform while on the road and can have real-time information on traffic and estimated travel time across different routes that enable them to take the best possible path (physical) to reach their destination.

The usefulness of the CPS springs from their properties of interoperability, connectivity, networking capability, communication, decentralization, autonomy, and modularity [14]. Interoperability allows a CPS to exchange mutually understandable data between its components whereas connectivity between components via various communication protocols enables this exchange. A unique characteristic of CPS is their modularity which enables a CPS to change and reconfigure its response in accordance with the users' needs and convenience. For that purpose, a CPS — an interconnected network of components or subsystems — needs to have networking capability for all subsystems to interact with one another simultaneously to complete target actions without losing their autonomy in decision-making and decentralized control capabilities.

This direct interaction of different components with one another for making real-time decisions characterizes the uniqueness of CPS [15] compared to traditional critical infrastructure systems. At the same time, it also poses the challenges of modeling the decision-making process of each agent within a CPS to maximize the combined benefits while maintaining system constraints [16]. In particular, in cases where rational agents with conflicting interests interact with one another, it becomes an extremely challenging task to model their complex interaction by deciding whether they should either cooperate or compete with one another to attain specific objectives. Examples of such objectives include, but are not limited to, reducing costs [17], maximizing revenue [18], balancing supply and demand [19], confirming reliability and security of the system [20], promote visibility and care [21], and ensuring the sustainability of the environment and system operation [22]. This necessitates such a decision-making process to be based on solid mathematical foundations that can ensure an efficient and secure operation of the CPS.

Given this context, *game theory* is a natural approach to model interactive decision-making in CPS. Game theory is a formal analytical and conceptual framework with a mathematical toolset that enables it to model complex interactions among self-interested players [23]. It has been used in a wide variety of disciplines including economics [24], finance [25], operational research [26], energy [27], social science [28], political science [29], psychology [30], military [31], and retail markets [32] for several decades.

In recent times, a large volume of interesting research has also been reported in the literature focusing on game-theoretic approaches for CPS [33]. Since the types of CPS are diverse due to their difference in applications and the pattern of agents' interactions within each system, the key research question that arises is whether it is possible to grasp the entire scope of how game theory can be used to model the operation of CPS. To answer this question, this paper provides a comprehensive understanding of the state-of-the-art game-theoretic research in the area of CPS to help researchers: 1) to conduct new research requiring agent interactions within the CPS, 2) to be prepared to address new challenges that may arise in CPS, 3) to design and implement operational algorithms for CPS that are efficient and cost-effective, and 4) to develop new services that can be offered by CPS. By presenting clear insights into the recent advances in the game-theoretic study of CPS, this article can be helpful for new researchers in the area of energy, engineering, economics, signal processing, medicine, agriculture, and transportation.

The main contributions of the paper can be summarized as follows:

- We provide a detailed background of different types of CPS and their general structure.
- We comprehensively discuss different types of game-theoretic approaches that are suitable for and have been used in CPS research.
- We identify and explain the relevance of game theory for CPS given their various characteristics.
- We review how game theory has been used in different areas of CPS research.
- We identify and discuss a number of challenges for future CPS implementations that can be addressed by using game theory.

We note that there are several recent survey papers that are relevant to CPS research. For example, in [16], the authors have discussed how game theory can contribute to shaping the future of peer-to-peer energy sharing in the electricity market. The operational requirements of communication networks for electric system automation are featured in [34]. In [35], the authors have provided an overview of CPS research from a closed-loop system perspective. A comprehensive overview of the properties of CPS and guidance on how a CPS architecture can be tailored from a provided framework are discussed in [36]. The Reliability and security issues of CPS are surveyed in [37], [38], and [39]. A review of blockchain-based security and operation of CPS is given by the authors in [40] and detailed explanations of the relevance of CPS for industrial processes can be found in [41].

Clearly, these reviews have contributed significantly to the body of CPS knowledge giving researchers a good understanding of various aspects of CPS. Their foci are either on a specific area of CPS such as energy systems and industrial CPS or on a particular property of a CPS such as security. Thus, they are more suitable for readers who have some prior knowledge of different types of CPS and their characteristics. This paper, on the other hand, *is written for readers with no (or very limited) knowledge of CPS and applications of game theory in CPS research.* Therefore, we first provide readers with necessary background information on different types of CPS and their general structure. Then, after a discussion of some elements of game theory, we illustrate why game theory is one of the most relevant approaches to deal with challenges in CPS research and how existing studies have utilized it. Further, this paper differs from existing review articles in terms of the arrangement of contents, the focus of discussion, and the identification and explanation of future challenges. We note that experienced researchers will also benefit from this work to enhance their comprehension of the topic.

The rest of the paper is organized as follows. In Section II, we provide a comprehensive background on CPS followed by a review of different game theoretic approaches in Section III. The relevance of game theoretic approaches in CPS research and a detailed overview of applications of game theory in various CPS research are given in Section IV. Finally, the paper is concluded in Section V.

## II. OVERVIEW OF CYBER-PHYSICAL SYSTEMS

As an emerging research area, investigations of CPS involve multiple overlapping disciplines of science and engineering. Consequently, the formal definition of the CPS has also evolved based on different perspectives from different scholars. In [42], CPS is defined as a technical platform where physical processes affect computations through a feedback loop and vice versa [43]. The authors in [44] defined CPS as a network physical engineering system that monitors and controls the operations of physical systems through computations. In summary, a CPS is a system that features a compact combination of, and coordination between physical systems and digitally networked systems [45] through a feedback loop. In this paper, we formally define CPS as follows:

*Definition 1:* A CPS is a system that brings both a physical system and a digital (or cyber) networked system together under the same framework, where the activities in the physical system can be monitored, analyzed, and controlled by the computational ability, agility, and adaptability of the digitally networked system, via communication through a feedback loop between the two systems. A completely autonomous CPS can learn from the surroundings and make decisions and operate independently in real-time, whereas a semi-autonomous system operates independently only in predefined conditions.

### A. ARCHITECTURE

The architecture of a CPS depends on its type and functionalities. However, according to the definition, each CPS, in general, needs to 1) create a digital twin of its physical structure for real-time monitoring and analysis, 2) have an intelligent control unit for estimation and decision-making, and 3) a unit for executing algorithms to execute the decision in the physical structure through a feedback control loop. To perform these regular applications, the architecture of a CPS has five levels, as shown in Fig. 1, irrespective of its specific type and purpose [46]. These are a smart connection level; a data-to-information conversion level; a cyber level; a cognition level; and a configuration level.

#### 1) SMART CONNECTION LEVEL

To create a digital domain of a physical system for monitoring, analysis, and decision-making purposes, the first step is to acquire accurate and reliable data from different components of the physical system [47]. For accurate collection and measurement, IoT has become popular as the data acquisition tool [48]. The concept of IoT is derived from networked smart devices [49], and an integrated IoT allows the monitoring and sensing of various environmental and mechanical parameters of a CPS in real-time, collecting the information accurately, and passing the information to the server through using appropriate communication protocols, e.g., 5G [50]. Two important factors need to be considered in the smart communication level of the CPS. First, considering various types of data that stem from different components of the CPS, a seamless and tether-free method for the acquisition of data needs to be established [51]. Second, secured communication protocols need to be confirmed for data transfer from the IoT devices to the server [52]. Further, selecting appropriate sensors (specifications) to collect data from different machinery and components is also important [46].

#### 2) DATA-TO-INFORMATION CONVERSION LEVEL

Timely access to data and information is the key to the success of any business and it is also true for the successful implementation of the CPS. Data conversion aims to discover correlations and hidden patterns with the purpose of extracting useful information. Collected data from different components of the CPS can be divided into three types [53]: structured data, semi-structured data, and unstructured data. For structured data, a distributed database system is used for management and storing purposes. To store unstructured data, Hadoop distributed file system and not only structured query language is popularly used [53]. Finally, semi-structured data are unified into a standardized format by extensible markup language and stored in either a relational database management system or distributed database system. To extract meaningful information from the acquired data, an effective data-to-information conversation level is needed. The most widespread technique is data mining [54]. In general, data mining techniques analyze large volumes of data to discover

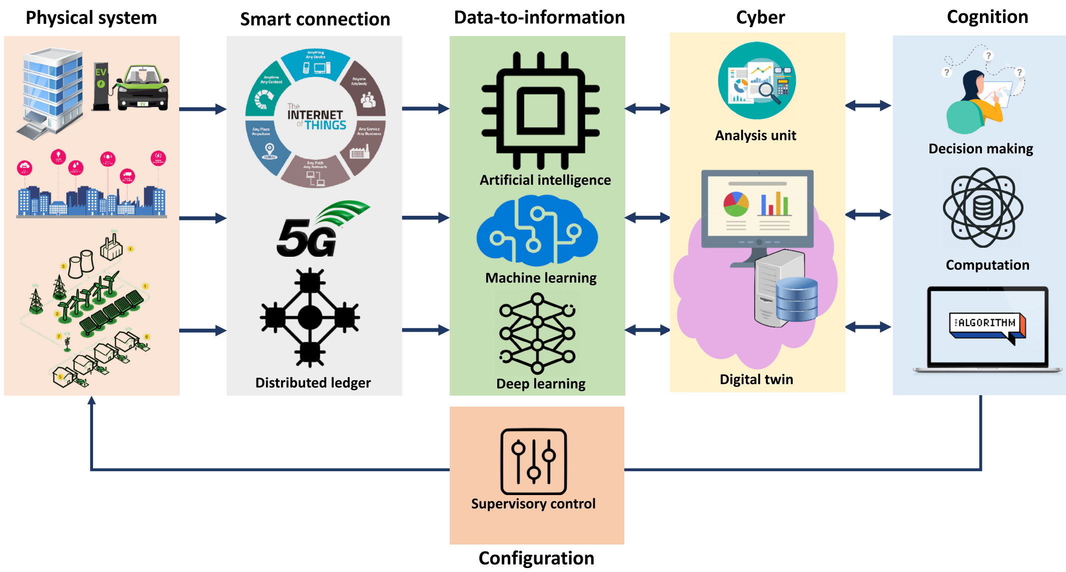


**FIGURE 1. This figure gives an illustration of how different levels integrate the cyber and physical spaces of an operational CPS - inspired by [46]. These levels enable CPS to collect real-time data from the physical world, construct cyberspace (digital twin), and provide analytics and computational capabilities in cyberspace to create control signals to manage the physical system for specific tasks and objectives.**

useful, interesting, and valuable structures [55]. Popular data mining techniques that have been used in the CPS include clustering [56], classification and regression [57], artificial intelligence [58], deep learning [59], Bayesian learning [60], and machine learning [61].

#### 3) CYBER LEVEL

The cyber level is the central information hub [46], where information is being pushed from every connected component within the network to form the digital twin of the physical structure [62]. According to IBM [63], a digital twin is a virtual representation of a system that is built and updated from real-time data and uses simulation [64], machine learning [65], and reasoning [66] to assist decision-making. Hence, all information is being managed, analyzed, and benchmarked in this level of the CPS which helps to optimize the decision made at the cognitive level. Unfortunately, this level is also the primary target of hackers and prone to security breaches [67]. As a result, the security of the cyber level is of paramount importance for a secured and optimal operation of the overall CPS [68], [69]. Extensive research on the cyber-physical system security has been reported for green buildings [70], smart grids [71], [72], [73], [74], [75], transportation systems [76], [77], [78], medical CPS [79], [80], [81], autonomous robot system [82], [83], [84], smart city [85], [86], [87], and smart agricultural system [88], [89], [90].

#### 4) COGNITION LEVEL

This level of a CPS helps to take correct decisions about actions in the physical structure of the system. Decisions are taken based on comprehensive knowledge of the monitored system and the analyzed information at the cyber level [46]. CPS addresses issues relevant to both human and artificial cognition. For example, CPS can take over particular cognitive tasks from the users, and through the exchange of information with them, it can produce the necessary useful outputs [91]. In doing so, the cognitive level relies on various computational models [45], develops algorithms [92], and produces control signals to execute various actions in the physical structure of the CPS.

#### 5) CONFIGURATION LEVEL

Configuration level acts as a supervisory control of the overall CPS [46] that applies the corrective and preventive decisions taken in the cognition level to the physical space of the CPS. Thus, if there is any change in the circumstances in the physical space, it is monitored, recorded, and analyzed at the cyber level and subsequent necessary actions are planned at the cognition level. Then, to adjust the quality and efficiency required for the newly adopted circumstances, the configuration level executes necessary control actions in the physical space [93].

### B. ATTRIBUTES

The five-level architecture empowers CPS with various attributes to efficiently function in different application domains. Examples of such attributes include adaptive control, data-driven, predictive maintenance, inter-connection between systems, Internet-of-Things, real-time monitoring and control, human-machine interaction, and security and privacy.

#### 1) ADAPTIVE CONTROL

Adaptive control can be defined as the ability of a CPS to modify its mode of action with the changing environmental factors to achieve the best possible outcome. For example, in medical CPS, respiratory modules are used to assist patients to breathe. These modules are capable of tracking time-varying target pressure, estimating the hose characteristics of the module, and adjusting the pressure over the hose according to the need of the patient [94]. In smart agricultural and autonomous robotic systems, applications of adaptive control can be found in irrigation and moisture distribution [95] and military surveillance and intervention [96] respectively. Similarly, adaptive control is used in green buildings for heating, ventilation, and air-conditioning (HVAC) and lighting control based on occupancy [97], in smart grids for price-signal enabled demand response [98], in transportation for coordinated control of electric vehicles [99], and in manufacturing for laser welding and additive manufacturing [100].

#### 2) DATA-DRIVEN

Since the beginning, data has been an integral part of the CPS. The working principle of a CPS revolves around interactions between the physical and cyber systems enabled by the flow of data between them. Thus, CPS can alternatively be defined as a data-driven system. The management, control, and performance of different subsystems in a CPS are therefore highly impacted by the data obtained from different relevant sources and a large number of data-driven techniques and algorithms have been proposed over the last decade. For example, in the smart grid, the security of the CPS is a major concern and data-driven approaches have been used to address this issue [101]. In green buildings, heuristic data-driven algorithms are used to control the set-point temperatures of air-conditioning systems based on environmental conditions and people's preferences to reduce the electricity bill [102]. In [103], the authors have discussed the importance and use of IoT data for medical imaging, whereas similar applications of data in a smart city are shown in [104] and [105]. The extensive application of data has also been demonstrated in transportation systems [106], robotics systems [107], agricultural system [108], and industry 4.0 [109].

Another important aspect of these data-driven CPS is the reliability of the data. With the recent emergence of affordable sensors and sophisticated data acquisition systems along with better communication speed, it is now possible to collect the large amount of data produced by the inter-connected facilities of the CPS. For example, a single machine in a manufacturing plant can generate thousands of production and health monitoring information within seconds that can be translated to several trillions of records of data per year [110]. Since, these data are being used by the cyber and cognition systems of a CPS to have an overall understanding of the current state of the physical system, forecast the variation of different environmental parameters, and subsequently decide the action plans to control various appliances of the physical systems, the reliability of data is of paramount importance in CPS [111]. Examples of recent research that discussed the reliability of data acquisition, data communication, and data processing in the CPS can be found in [112] and [113].

#### 3) PREDICTIVE MAINTENANCE

Extensive use of data enables CPS to perform predictive maintenance, which is a technique that utilizes data analysis tools and techniques to identify anomalies in the operation of different subsystems and estimate possible defects in equipment and processes to fix them before failure. Predictive maintenance has been successfully done in green buildings for HVAC and home automation systems using machine learning techniques [114] and found its application in medium voltage switch gear to enable energy and mobility revolutions in the smart grid [115]. In the transportation sector, such as in railways, faults in the pantograph and catenary systems significantly increase the risk of fatal incidents. Periodic or post-fault maintenance of these systems is also expensive. Hence, by obtaining data from the railway, predictive maintenance not only reduces the cost of sustenance but also reduces the probability of casualty substantially [116]. Further applications of predictive maintenance can also be found in manufacturing plants. For instance, in [117], an online technique is developed for real-time anomaly detection of equipment in a manufacturing plant using hierarchical temporal memory that can learn and adapt continuously and robust to noise. Similarly, predictive maintenance can also contribute to improving the performance of the CPS in medical [118], agriculture [119], and robotics [120].

#### 4) INTER-CONNECTION BETWEEN SYSTEMS

An important trait of CPS is the interconnectivity between its different elements. In a smart city, for example, green buildings with smart building management and automation system are connected with one another and can share energy, water, and other resources among themselves [121]. An example of such a community is shown in Fig. 2. By communicating with one another, different agents within a CPS interact to achieve individual and collaborative goals by taking informed actions. In doing so, each may act selfishly and competes with other agents with limited or complete access to environmental information and others' action plans to achieve its own objectives such as reduction in cost [122], balancing between demand and supply of resources [123], increase access to community resources [124], and improve communication for critical operations [125]. On other hand, agents may also work together and cooperatively take decisions to obtain goals that bring collective benefit to the overall CPS. Examples of such cooperation are available in green buildings [126], robotics [127], smart grid [128], transportation system [129], and manufacturing plants [130].

#### 5) INTERNET OF THINGS

The interconnection and transfer of data between different subsystems of CPS have been possible due to the emergence of IoT (Internet of Things). IoT can be defined as the wireless

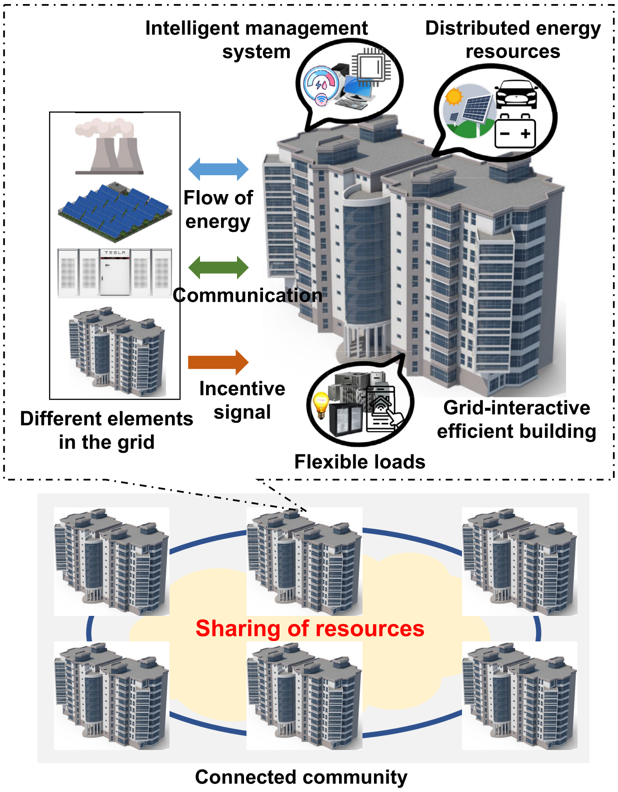


**FIGURE 2.** An illustration of how different green buildings of a smart city can be interconnected with one another and share resources among themselves for self-sustainability.

network that enables the pervasive presence of a variety of objects (or things) through Radio-Frequency Identification (RFID) tags, sensors, actuators, and mobile phones and makes the objects interact with one another and cooperate with their neighboring objects to attain the common objectives [131]. The application of IoT is critical and extensive in the CPS. For example, IoT's highly integrated and open nature is ideal for smart agriculture that enables integration of autonomous equipment from various organizations for irrigation, weather forecasting, and social media stream for rapid events including threats, floods, and earthquakes detection [132]. By providing a platform for communication between different appliances within green buildings, IoT can not only help the owners of the building to reduce the use of unnecessary resources and thus cost [133] but also enable them to share the unused resources with other peers within the community for better sustainability [134]. Typical examples of such roles of green buildings are found in smart cities [135] and smart grids [13]. In robotics, IoT has been proven to be essential for designing multi-robot systems in industrial and academic areas [136]. In particular, the localization of robots is more reliable when robots can cooperate with an IoT-based smart environment [137]. Further, detailed discussions on the application of IoT for manufacturing and medical services can be found in [138] and [139].

### 6) REAL-TIME MONITORING AND CONTROL

The use of IoT has made it possible for the CPS to monitor the function of its different subsystems in real-time, timely acknowledge the variations in environmental framework, and take perceptive and intelligent decisions accordingly. Through the use of digital twins, now it is possible in large manufacturing plants to scrutinize and mentor every stage of the production process to ensure mass production of high-quality commodities in shorter time frames [140]. Continuous monitoring of critical patients and providing real-time telemedicine services either onsite or remotely is also possible now in medical CPS. For example, in [141], the authors argue that telemedicine could be an effective way to improve the overall health care of cardiovascular disease with a reduced health cost, while [142] shows how real-time monitoring of patients conditions can save many lives through automatic management of oxygen saturation. Continuous monitoring of activities of different subsystems and control of their actions for more productive outcomes are also very common in green buildings [143] - for HVAC, lighting, and flexible appliances control; smart grid [144] - for auditing of phase measurement units and security; transportations [145] - for coordinated charging and discharging of electric vehicles; agriculture [146] - for adaptive irrigation; and robotics [147] - for localization and routing control.

### 7) HUMAN-MACHINE INTERACTION

Human-machine interaction (HMI) refers to the communication and synergy between a human and a machine that is usually done through a graphical user interface. The agent-based architecture of the CPS enables its different agents to directly communicate with humans to take instructions for accomplishing certain tasks. Extensive use of HMI can be found in medical CPS, smart grid, robotics, transportation, and manufacturing. In medicine, for instance, in [148], the authors present a touchless and gesture-based HMI framework for the operating room to enable surgeons to define a personalized set of gestures to control the arbitrary medical computerized systems. HMI also finds its application for smart grids where energy customers directly set their preferences over the web [149] to set parameters and preferences for participating in demand response programs. In robotics, HMI is used for designing rehabilitation robots and socially assistive robots to augment the efforts of caregivers, parents, and educators [150]. The practice of HMI can be found in developing automated vehicles [151] and digital twin-based smart manufacturing [152] in the domain of transportation and manufacturing respectively. Finally, HMI is also used in precision agriculture for the real-time display of various sensor data on temperature, humidity, and solar irradiation and enabling users to control the overall agricultural CPS [153].

### 8) SECURITY AND PRIVACY

Due to the highly interactive nature of the decision-making process and significant use of data, maintaining the security of the system and preserving users' privacy have become major concerns for CPS. It is estimated in [154] that cyber-crime will cost the world about $10.5 trillion annually by 2025. In particular, smart grids, smart cities, green buildings, medical facilities, agricultural farms, and manufacturing plants are most vulnerable to cyber attacks for extensive use of IoT, where controlling and monitoring are based on Internet-based protocols. As such to maintain the secured operation of CPS, novel preventive methodologies and security architectures are developed. For example, in [155], the authors demonstrated how artificial intelligence can be utilized as a key tool to save green buildings from cyber attacks. Artificial intelligence is also proven to be very effective in protecting smart grids, intelligent vehicles, and smart cities from hackers by developing adaptive baseline behavior models, effectively detecting new, unknown attacks by combining known and unknown data sets based on predictive analytics and machine intelligence, as discussed in [156], [157], and [158] respectively. Other examples of technical approaches that have been used to develop security measures for CPS include big data analysis [159], cryptography [160], machine learning [161], deep learning [162], and distributed ledger technology [163]. Importantly also, for making data available from CPS, and sharing, provably private transformations are required that retain data utility, a comprehensive survey of such relevant differentially private techniques for CPS is provided in [164].

A short review of the attributes of CPS that make game theory an appropriate tool to model its decision-making and control framework is given in Table 1.

### C. TYPES

Different attributes enable CPS to operate in different application domains. Depending on these applications, there are different types of CPS that operate either independently or in a coordinated fashion to deliver services that are environmentally friendly, reliable, secured, efficient, agile, and cost-effective. The purpose of this section is to introduce the readers to selected CPS that have particularly found many game theoretic applications.

#### 1) GREEN BUILDINGS

Green buildings - also known as smart or intelligent buildings - are buildings with capabilities to gather information and respond to it [165]. With a major focus on sustainability, green buildings are equipped with modern technologies including 5G, artificial intelligence, Internet-of-Things (IoT), and cloud and edge computing that make them energy efficient and human friendly [166]. Like other CPS, the building management system (BMS) in a green building monitors the building's health and environment in real-time through its data collection systems (IoT and sensors), measures the physical built environment, and sends data to its control center for analysis and operational control of the building [48]. Key mechanics that shift the building paradigm from ordinary buildings to smart buildings include 1) IoT for seamless integration and processing of building environmental parameters such as temperature, noise, humidity, electricity and water flow, human activity information, and estimation of energy usage [48]; 2) BMS for controlling building operation according to human needs and activities [167]; 3) Flexible loads for scheduling and administering of household activities [168]; 4) big data management for analysis and forecasting [169]; 5) artificial intelligence for automatic, well-informed, and real-time decision making [170]; and 6) distributed energy resources for increasing use and management of green energy [171]. A graphical illustration of green buildings is shown in Fig. 3.

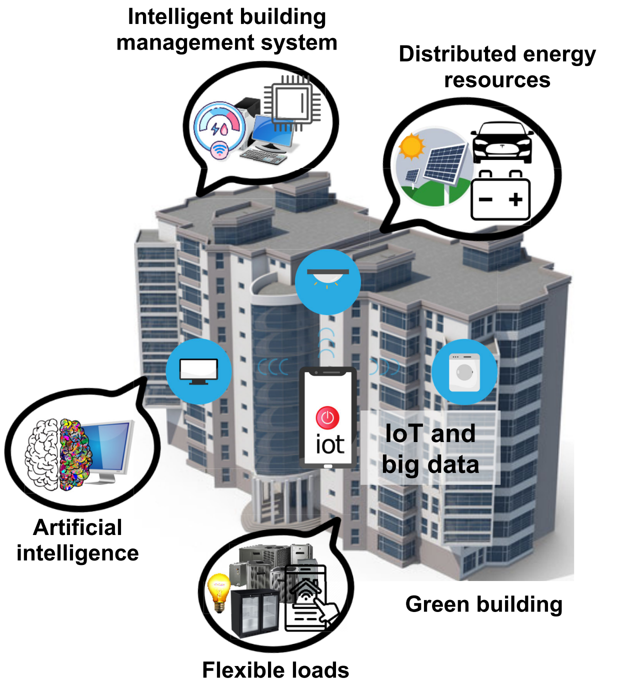


**FIGURE 3. This figure gives a graphical illustration of a green building. The building is equipped with flexible loads and distributed energy resources. The intelligent building management system received real-time information about the building's environment through its IoT system and makes intelligent and real-time informed decisions using artificial intelligence techniques based on the received big data.**

#### 2) SMART GRID

A smart grid - also known as smart power grid [173] - utilized modern information technologies to deliver power more efficiently by responding to a large spectrum of conditions and events. According to the National Institute of Standards and Technology (NIST) [174], the smart grid consists of seven domains including customers, markets, service providers, operations, bulk generation, transmission, and distribution (Fig. 4). The heart of the smart grid that reflects its properties as a CPS is the smart infrastructure system consisting of a smart energy subsystem, smart information subsystem, and smart communication subsystem [175]. The smart energy

**TABLE 1. Summary of attributes of CPS that make game theory an appropriate tool to model its decision-making and control framework.**

| Attributes | Brief overview | Example | References |
|---|---|---|---|
| Adaptive control | A CPS has the ability to modify its mode of action with the changing environmental factors to achieve the best possible outcome. | In medical CPS, respiratory modules are capable of tracking and adjusting the time-varying target pressure over the hose according to the need of the patient. | [94]–[100] |
| Data-driven | The working principle of a CPS revolves around interactions between the physical and cyber systems, which is enabled by the flow of data between them and the authenticity of the data. | Heuristic data-driven algorithms are used in green buildings to control the set-point temperatures of air-conditioning systems to reduce the electricity bill. | [101]–[113] |
| Predictive maintenance | A CPS performs predictive maintenance by utilizing data analysis tools and techniques to identify anomalies in the operation of different subsystems and equipment and fixes them before failure. | Online techniques are used for real-time anomaly detection of equipment in manufacturing plants by using hierarchical temporal memory that can learn and adapt continuously. | [114]–[120] |
| Inter-connected system | Interconnectivity between different subsystems within a CPS enables different agents to achieve individual and collaborative goals by communicating with one another and taking informed actions. | Green buildings with building management systems can be connected with one another and share energy, water, and other resources among themselves for efficient resource management. | [121]–[130] |
| Internet-of-Things | The interconnection and transfer of data between different subsystems of the CPS are enabled by IoT devices and protocols. | IoT in smart agriculture enables the integration of autonomous equipment from various organizations for irrigation, and use of weather forecasting, and social media stream on rapid events including threats, floods, and earthquakes for intelligent farming. | [13], [131]–[139] |
| Real-time monitoring and control | A CPS can monitor the function of its different subsystems in real-time, timely acknowledge the variations in the environmental framework, and take perceptive and intelligent decisions accordingly. | Continuous monitoring of critical patients and providing real-time telemedicine services either via onsite or remotely is also possible now in medical CPS. | [140]–[147] |
| Human-machine interaction | The agent-based architecture of the CPS enable its different agents to directly communicate with humans to take instructions for accomplishing certain tasks. | Application of HMI can be found in a smart grid where energy customers directly set their preferences over the web to set parameters and preferences for participating in demand response programs. | [148]–[153] |
| Security and privacy | Maintaining the security of the system and preserving users' privacy have become major concerns for CPS, for which an estimated $10.5 Trillion annually will be spent globally by 2025. | Recently, smart grids all around the world have been targeted by hackers to take control of the power systems and hence security research has become of paramount importance in this domain. | [154]–[163] |

subsystem enables advanced power generation, distribution, and consumption. In contrast to the traditional power grid, the power generation and flow pattern are more flexible in the smart grid due to the integration of distributed energy resources [176]. However, flexibility in power generation also makes power flow control much more complicated. The role of the smart information subsystem is to provide advanced information management [177] including data modeling, information analysis, integration, and optimization, enables business settlement and transactions [178], and facilitate real-time monitoring and management of devices in the smart grid [179]. The smart communication subsystem of the smart grid provides the platform for connectivity and information transmission among systems, devices, and applications. The communication subsystem consists of different types of networks including enterprise bus, wide area networks, field area networks, and premises networks. For efficient operation of the smart grid, it is important that the communication subsystem supports the Quality of Service of data [180], is highly reliable with a high coverage [181], and guarantees security and privacy.

### 3) INTELLIGENT TRANSPORTATION SYSTEMS

The idea of intelligent transportation systems was conceptualized and developed in the 1980s when cognitive information was incorporated into the road infrastructure and vehicle [182]. Since then, the transport sector has evolved immensely. In particular, as accidents and fatalities that are affecting both the economy and environment adversely in rising every year [183], the need for next-generation

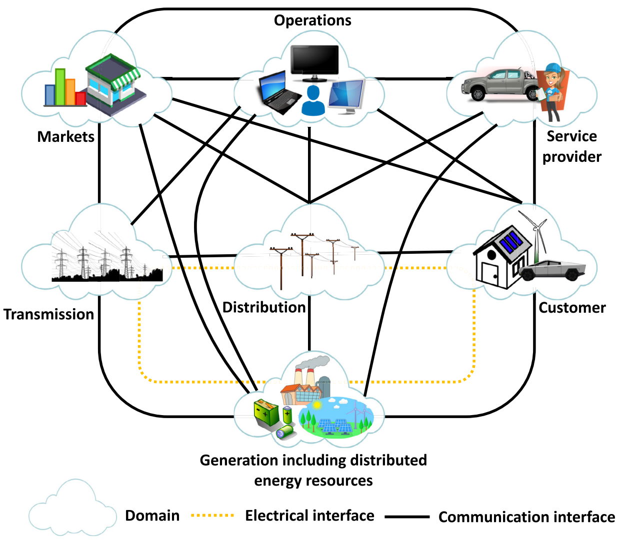


**FIGURE 4. This figure gives a graphical illustration of the conceptual model of smart grid as proposed by the NIST [172].**

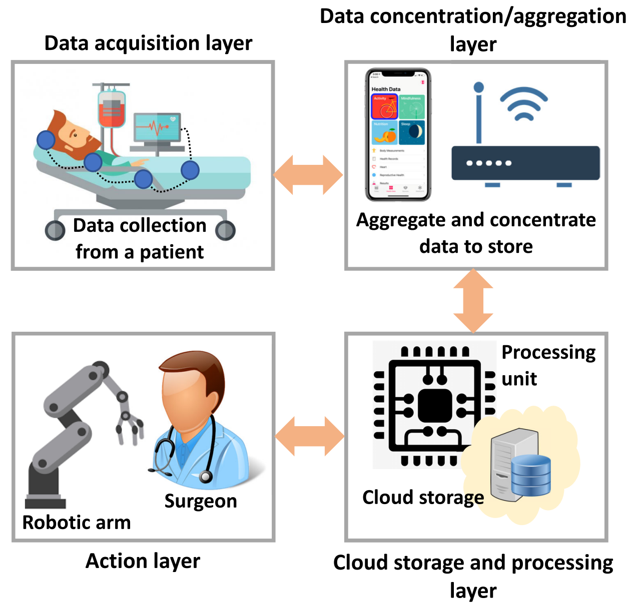


**FIGURE 5. This figure gives a graphical illustration of four layers of a Tele-medical system including data acquisition layer, data concentration/aggregation layer, cloud processing, and storage layer, and action layer. These layers enable a Tele-medical system to collect patient information, aggregate it, and process it to make actionable items to save lives.**

transportation systems in air traffic, car control, and railway leveraging advanced computing and sensing capabilities has increased significantly to improve safety and throughput. Now, intelligent transportation systems can enable vehicles to avoid traffic congestion [184], reduce energy and land consumption [182], improve driving control, safety, and security [185], act as a distributed energy resources to provide a balance between electricity demand and supply [186] and reduce cost (or, increase benefit) for the vehicle owner [187], and improve environmental sustainability [188]. Disrupting technologies and innovating tools that are contributing to revolutionizing the transport system for a safer and greener future include in-vehicle sensor technology [189], in-roadway sensors [190] and over-highway sensor technologies [191], IoT and cloud services [192], tools for big data analysis [193], artificial intelligence [194], traffic sensing technologies [195], distributed ledger technology for transportations [185], and vehicle-to-vehicle communication and network [196].

#### 4) TELE-MEDICAL SYSTEMS

Tele-medical systems are networked systems of medical devices that provide life-critical and context-aware services in hospitals for high-quality continuous care for patients [197]. For example, at present, the advancement in medical sensors, wireless sensor networks, and cloud computing has transformed the monitoring and computation processes of a stand-alone system to a remote monitoring system by overcoming the geographical barrier [198]. Thus, it is now possible to provide patients with both in-home and in-hospital care. The Tele-medical system also provides a platform for using necessary computational resources to make intelligent decisions about a patient's conditions based on the analysis of the patient's historic data from the digital record and real-time data from smart devices and bio-sensors based monitoring systems [199]. To successfully provide life-critical services, a typical Tele-medical system architecture consists of four layers [79] including a data acquisition layer, data concentration/aggregation layer, cloud processing, and storage layer, and action layer. The data acquisition layer is responsible for collecting patient medical information and passing this information to nearby computationally-capable devices. The data concentration/aggregation layer concentrates data from each device in the data acquisition layer, aggregates them, and sends them to the cloud. Cloud processing and storage layer securely store patient information in the cloud, process the data following the privacy-preserving procedure, and uses advanced analytics to support health professionals to make informed decisions about patients. Finally, the action layer provides either passive (ECG monitoring) or active actions (robot-assisted surgery [200]) for the medical treatment of patients. An overview of these four layers is shown in Fig. 5.

#### 5) AUTONOMOUS ROBOTIC SYSTEMS (UAV/UGV)

Autonomous robotic systems such as unmanned air vehicles (UAV) and unmanned ground vehicles (UGV) are becoming very popular as the next generation CPS [201]. A UAV is commonly known as a drone, which can fly like an aircraft without any human pilot or any person on board [202]. UGVs, on the other hand, are robotic systems that operate on land without any onboard human operator [203]. Thus, as the term "unmanned" indicates, both UAV and UGV operate without an onboard human operator but may be controlled through a fixed control station [204]. Some unmanned systems also act completely autonomously without any human intervention during their operation [205]. Autonomous robots can travel either between two pre-defined points or need to adapt to the environment based on surrounding information to complete their mission. Hence, depending on application areas, autonomous robotic CPS are built upon simultaneous localization and mapping techniques [206], accurate data acquisition and processing units [207], machine learning and artificial intelligence computation tools [208], and secured and low latency communication and control procedures [209], [210]. The cyber domain and the physical domain of autonomous robotic CPS are tightly connected with the coupling effect. According to [211], the coupling effect can have two meanings: 1) the macroscopical data that flows from the physical domain to the cyber domain for analysis and processing to take effects in the physical domain again; and 2) the mutual reliance between different components in cyber and physical domains in a micro level. To implement a complete and operational autonomous robotic CPS, understanding these coupling effects is critical to smoothly operate UAV and UGV with constrained communication, computation, and control resources [212].

#### 6) SMART CITIES

A smart city, as the name implies, is an urban area that utilizes technologies to become connected and agile to address 21st-century environmental, social, and economic challenges and improve the quality of life of its citizens. It comprises of several CPS operating simultaneously to address the challenge of reducing infrastructure risk in the smart city [213], improving information and operational security [214], and making a balance between financial impact and operational and safety impacts on the people in the smart city [215]. The concept of a smart city encompasses a wide range of applications that constitute the backbone of any municipality. For example, a smart city should have access to the smart digital health system [216] fueled by modern bio-compatible and accurate sensors, advances in body area network [217], and reliable and ubiquitous communications [218]. To improve the safety of roads in a smart city and provide drivers with a more convenient driving experience, intelligent transportation has become an essential part of a smart city. Smart driving applications employ different technologies to evaluate the status of the road and traffic conditions and help the drivers with real-time status updates [219]. Smart transportation can also help drivers to find a cheap and vacant parking spot in a busy city [220].

A smart grid is another application domain within a smart city that improves the efficiency of power generation, distribution, and consumption with reduced costs, pollution, and positive environmental impact. Houses and buildings in smart cities are equipped with their own solar and storage systems and an implication of this adoption of distributed renewable resources is the increased use of real-time pricing [221], demand-response management [222], peer-to-peer energy sharing [223], and energy security [224]. Meanwhile, buildings in a smart city are expected to be green buildings with smart appliances, adaptive control systems, own energy generation and energy storage facilities, and necessary securities services [215]. Buildings are able to be connected to one another for sharing resources such as energy [13] and become self-sustainable as a connected-community [121] when needed. Finally, public safety service is another key focus of smart cities to ensure people's security and safety - especially under unusual circumstances such as natural disasters and political unrest [215]. Firefighters, police, and medical staff should respond promptly when needed and provide the affected people with necessary services by using state-of-the-art technologies. However, in times when technologies are down due to a disaster, alternative solutions are needed for these emergency departments to communicate and offer services [215]. An overview of how such a diverse set of CPS can co-exist and work together to make a smart city operational is shown in Fig. 6.

#### 7) SMART AGRICULTURAL SYSTEMS

By 2050, the world population will exceed 9.0 billion [225]. To feed this huge number of people, significant challenges have to be overcome to achieve the desired level of agricultural productivity under stringent constraints of limited resources, less skilled labor, less arable land, and climate change. Precision agriculture [226] - a smart CPS-based farming practice - has emerged as one potential solution to address this grand challenge. Precision agriculture has embraced autonomous, data-intensive, and disruptive technologies to locate and quantify spatial variability of soils, develop tools to enable precision management of crop nutrition, and use the current exponential volume of data to make decisions about 'site, plant, and animal-specific management decisions to improve efficiency, productivity, quantity, profitability and sustainability of agricultural production' [227]. With the advancement of the Internet of Everything (IoE) [228], land becomes a substrate in smart agriculture where different kinds of sensors acquiring heterogeneous data are connected to the Internet through a rural network. The real-time collected data is stored in the cloud database and processed and analyzed to identify land characteristics and requirements. Then, appropriate decisions based on weather, site information, and market conditions are taken by the intelligent decision-making unit to send to either the domotic system [229] or the farmer in charge for action and treatment.

#### 8) INDUSTRY 4.0

By integrating innovating functionalities through IoT, IoE, big data analytics, cloud manufacturing, and fog computing, CPS has provided a great opportunity to build advanced industrial systems and applications - Industry 4.0 [46]. The Third Industrial Revolution of the late 1990s not only digitalized and automated industrial production through extensive

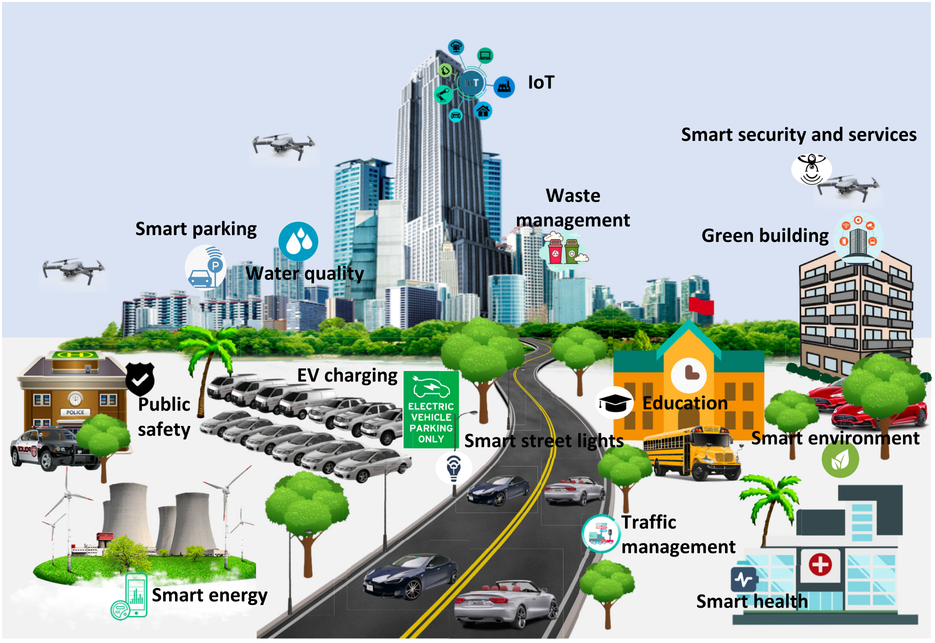


**FIGURE 6. This figure gives an illustration of smart city. A smart city can be thought of as a collection of different CPS including green buildings, smart transportation, smart energy grid, and connected communities to ensure a safe, convenient, and prosperous urban experience for its inhabitants.**

applications of electronics and computers but also laid the foundation blocks for Industry 4.0. Facilitated by the Industrial Internet of Things (IIoT), artificial intelligence (AI), autonomous robots, and smart digital technologies, today's Industry 4.0 creates a better interconnected, automated, and holistic manufacturing ecosystem, thereby offering higher efficiency [230], productivity [231], scalability and security [232], privacy [233], and the autonomous operation of production processes [234] by ensuring that different components including equipment, logistics systems, work-in-progress components, and others (including people) directly interact with one other to achieve collaboration. Therefore, cyber-physical systems are integral to achieving the vision of Industry 4.0, as CPS couples the physical productions and operations with the cyber systems through big data, augmented reality, cloud computing, and IoT to enable the seamless exchange of real-time information and commands.

## III. OVERVIEW OF GAME THEORETIC APPROACHES

The five-level structure and subsequent attributes enable different CPS to take real-time decisions on their action plans through interaction between their different components [236]. Due to these interactive characteristics of CPS, game theory [237] has been extensively used in the past decade to model the decision-making behavior of rational agents within a CPS by capturing their both competitive [238] and cooperative nature of interactions [239]. Essentially, game theory is a mathematical tool that conceives social situations among rational players and analyses their strategies in competitive environments where the outcome of a participant's action depends on the preferences and actions of other participants [240]. Applications of game theory can be found in economics [241], politics [242], engineering [243], defense [244], medical [245], marketing [246], and recently topics in the broader area of CPS [247].

Depending on how each player chooses strategies to optimize their objective, game theory can be divided into two categories: cooperative games and non-cooperative games. In general, cooperative games deal with a coalition of players and decide how players can appropriately divide the value of the coalition among themselves. Meanwhile, non-cooperative games study which moves players should rationally make. Further, some games can take the form of either a non-cooperative or a cooperative game depending on the modeling of players' interactions. In this paper, we refer to such games as hybrid games.

### A. COOPERATIVE GAMES

Cooperative game theory analyses the behavior of rational players when they cooperate and articulates the formation of coalitions that strengthen the players' standings in a game [235]. Both coalition games and Nash bargaining are considered cooperative games [16]. Coalition games study the formation of different types of the coalition of players within the game and their properties [16]. Commonly, a coalition game is expressed by the pair $(\mathcal{N}, \nu)$, where $\mathcal{N} = \{1, 2, \ldots, |\mathcal{N}|\}$ refers to the set of players who seek to form coalitions and $\nu$ is the value that players collectively receive for being associated with each coalition $\mathcal{S} \subseteq \mathcal{N}$. In the characteristic form of coalition game [235], the value $\nu$ of

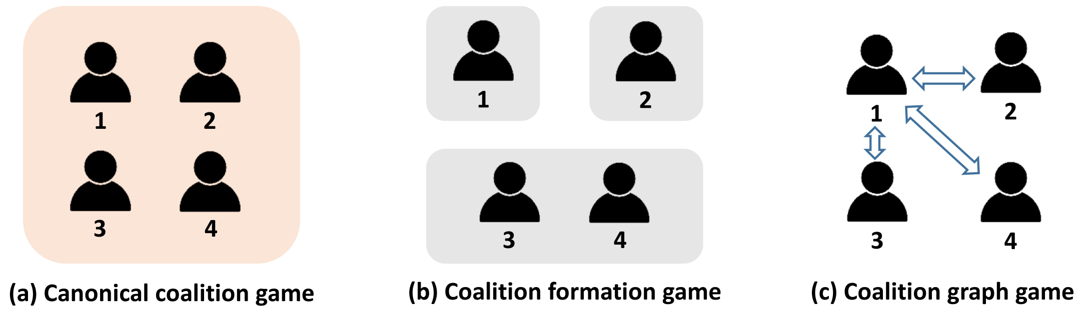


**FIGURE 7. This figure shows different types of coalition games including (a) canonical coalition game, (b) coalition formation game, and (3) coalition graph game. In a canonical coalition game, conditions for forming a grand coalition are the main focus of the study with a significant emphasis on how to stabilize the grand coalition. The formation of appropriate coalition structures and their properties are the foci of a coalition formation game. Finally, the coalition graph game establishes a grand coalition or a network of coalition structures using point-to-point communication between members of the coalition. This figure is inspired by Fig. 1 of [235].**

a coalition is set by the members of the coalition $\mathcal{S}$ and is not impacted by how the members in coalitions $\mathcal{N} \setminus \mathcal{S}$ are structured. As shown in Fig. 7, coalition games can be classified into three types: canonical coalition games, coalition formation games, and coalition graph games. Another branch of the cooperative game - Nash bargaining - on the other hand, focuses on the terms and conditions that players are required to follow to form different coalitions [248].

### 1) CANONICAL COALITION GAMES

Canonical coalition games have been widely formalized and meticulously understood. These games can be expressed with either a transferable utility (TU) or a non-transferable utility (NTU), in which the formation of a grand coalition of all players is never detrimental [16]. In other words, in a canonical coalition game, no group of players can less benefit by cooperating with one another compared to acting non-cooperatively. The main aims of coalition games are to study the properties of the grand coalition and determine how the profit resulting from cooperation can be distributed among the players in a fair manner [235].

The most common solution concept of canonical coalition game is the core [249], [250], which is directly linked to the stability of the grand coalition. Typically, the core of a canonical coalition game is a set of payoff allocations that confirms that no player will be better paid off by leaving the grand coalition $\mathcal{N}$ for another coalition $\mathcal{S} \subset \mathcal{N}$. However, it is not guaranteed that the core of a TU or NTU canonical coalition game always exists. In many instances, the core can be empty and the grand coalition is not stable. In these cases, alternative solution concepts such as the Shapley value and the Nucleolus are explored. The Shapley value [251] - introduced by the Novel Laureate Lloyd Shapley in 1951 [252] - was first characterized for TU canonical coalition games and later extended to NTU games. It takes into account the order in which the players in $(\mathcal{N}, v)$ join the grand coalition. If the players join in a random fashion, for example, the Shapley value allows payoff to each player according to its expected marginal contribution when it joins the grand coalition [235]. Although the Shapley value is unrelated to the core in general, it lies in the core for convex games [249], [250].

Another popular solution concept for canonical coalition games is the nucleolus, which is proposed mainly for TU games [250]. According to this solution concept, each player is provided with an allocation that minimizes the dissatisfaction of the players from the allocation they can receive in a given game $(\mathcal{N}, v)$. The nucleolus of a canonical coalition game exists and if the core of the game is not empty, it is in the core [235]. The applications of the nucleolus are many in game theory. One prominent application in the area of CPS is planning the power system expansion [253].

### 2) COALITION FORMATION GAMES

The network structure and the cost to form coalitions have major impacts on the solution of the coalition formation game. Like canonical coalition games, coalition formation games can also be in characteristic form with TU or NTU. However, unlike canonical games, coalition formation games can also be in partition form [254] and the gains that a coalition offers to its members are limited by the cost of forming the coalition [255]. Due to this reason, the composition of a grand coalition is very rare. In a coalition formation game, the main aim is to study the coalition structure including coalition type, coalition size, and stability of the overall structure. Since a network topology can be affected by environmental changes, the variation in player numbers, change is the characteristics of each player, and other factors can alter the stability of the coalition [256].

For solution concepts of coalition formation games, modified Shapley value, core, and nucleolus are used. Shapley value is referred to as $\mathcal{B}$ value with the restriction property [235]. The restriction property implies that for finding the $\mathcal{B}$ value, one needs to proceed in two steps: first, if there are $M = |\mathcal{M}|$ partitions as results of the coalition formation game, consider each partition $m \in \mathcal{M}$ of the game and determine the Shapley value $\phi_m$ of each partition of the coalition.

Second, determine the $\mathcal{B}$ value as the $1 \times M$ vector $\phi$ of payoffs implemented via combining the resulted allocation of each partition [235]. However, the restriction property does not apply to the core or the nucleolus [235]. With $\mathcal{B}$ present, the core and the nucleolus depend on the values of coalitions $B_m \in \mathcal{B}$ and the values of coalitions that are not in $\mathcal{B}$. Therefore, the analysis to find the core and nucleolus is more challenging than that of the Shapley value, the details of which can be found in [257].

### 3) COALITION GRAPH GAMES

In some scenarios, underlying communication between different components or agents within the CPS plays a major role to decide the utility and other characteristics of the game, for example, peer-to-peer energy trading in energy network [258]. Coalition graph game is ideal to model such scenarios with competitive players [259] by representing the connectivity between different players through graph [260]. In the graph form, a coalition game can be TU or NTU, but the value of a coalition is influenced by the external network structure. In particular, how different players are interconnected with one another strongly and significantly impact the properties and outcomes of the game [235]. The main aims of a coalition graph game are 1) to develop distributed algorithms for players who plan to build either a directed or undirected network graph and 2) to study the properties including stability and efficiency of the established network graph.

In the course of finding solutions for graph games, Myerson analyzed situations in which communication between players is restricted in TU games [261] and introduced the graph-restricted game, where the outcome of a coalition is determined by the total payoffs obtained in the original game by its connected subcoalitions [262]. Then, he proposed a solution concept - known as Myerson value [263] - for graph-restricted games. Myerson value is essentially the Shapley value of graph-restricted games that focuses on the player's characteristic function as the Shapley value and on its communication graph at the same time. Later, the Myerson value was also characterized in terms of component efficiency and fairness [264].

### 4) BARGAINING GAMES

Bargaining is an economic phenomenon that circumscribes negotiations, payoffs, and disagreement [265]. The modern theory of bargaining was proposed by John Nash in 1950 [266] as a two-player bargaining problem. In the Nash bargaining model, two players demand a portion of some commodity in different applications, e.g., energy trading [267], communication channel and power [268], and electric vehicle charging and discharging [269]. According to the bargaining solution, if the total amount requested by both players is less than the available quantity, both players can have what they requested. On the other hand, if the total requested amount is greater than what is available, none of the players gets their desired goods.

Different solution concepts are used for addressing bargaining problems. According to the solution approach proposed by John Nash [266], a bargaining solution should satisfy the properties of affine transformation invariant, Pareto optimality, irrelevant alternatives independent, and symmetrical property. The main principle of this solution is to maximize the product of surplus utilities of the players. Other bargaining solution concepts include Kalai-Smorodinsky bargaining solution [270] and Egalitarian bargaining solution [271]. The Kalai-Smorodinsky bargaining solution equalizes the ratios of maximal gains whereas by Egalitarian solution maximizes the minimum of surplus utilities.

## B. NON-COOPERATIVE GAMES

Non-cooperative games are the games in which no cooperation is allowed between players to support their decision-making process [272]. A $M$ players the non-cooperative game can be expressed by its strategic form as $\{\mathcal{M}, \{\mathbf{X}_m\}_{m\in\mathcal{M}}, \{U_m\}_{m\in\mathcal{M}}\}$, where $\mathcal{M} = \{1, 2, \ldots, M\}$ is the set of players, $\mathbf{X}_m$ is the strategy vector of player $m$, and $U_m$ is the utility that a player $m \in \mathcal{M}$ obtains for its choice of strategy $x_m \in \mathbf{X}_m$ [273]. The most popular solution concept of a non-cooperative game is the Nash equilibrium [240]. According to [274], in a $M$ player game, Nash equilibrium is a set of strategies, in which the actions of each player $m \in \mathcal{M}$ is its best response to the actions taken by the players in set $\mathcal{M} \setminus \{m\}$. Formally, Nash equilibrium is expressed as a vector of actions $\mathbf{x}^* = [x_m^*, \mathbf{x}_{-m}^*]$ such that $U_m(\mathbf{x}^*) \geq U_m(x_m, \mathbf{x}_{-m}^*)$, $\forall m \in \mathcal{M}$. $\mathbf{x}^*$ specifies a stable state of a non-cooperative game in which no player $m \in \mathcal{M}$ can increase its utility $U_m$ by taking an alternative action other than $x_m^*$ when the actions of players in set $\mathcal{M} \setminus \{m\}$ are fixed at $\mathbf{x}_{-m}^*$ [16]. The non-cooperative game can be divided into different categories with distinctive attributes and we provide a summary of each category as follows.

### 1) NON-ZERO SUM AND ZERO-SUM GAMES

In a non-cooperative game, if one player's gain (or loss) does not necessarily bring loss (or gain) to other players, the game is known as non-zero-sum game [275]. On other hand, in a zero-sum game [276], the sum of the objective functions of two players is zero - the gain of one player brings loss to another player and vice versa. Examples of non-zero and zero-sum games include the Prisoner's Dilemma [277] and chess game [278] respectively.

### 2) FINITE AND INFINITE GAMES

A non-cooperative game is called a finite game if each player of the game has a finite number of strategies. That is, each player can choose an action from a finite set of alternatives. An example of a finite game is chess. Finite games are also known as matrix games [272]. If a game is not finite, it is an infinite game. In an infinite game, the rules are changeable and the objective is to keep perpetuating the game. An example of an infinite game is the pursuit of excellence.

#### 3) DETERMINISTIC AND STOCHASTIC GAMES

A game is referred to as a deterministic game [279] is the players' strategies lead to completely predictable outcomes. A good example of a deterministic game is chess - the rules are specified and no additional variables are involved that may lead to variation in outcomes. In a stochastic game [280], on the other hand, the outcome of at least one player of the game is affected by an additional variable with a known probability function, for example, poker tournaments.

#### 4) COMPLETE INFORMATION AND INCOMPLETE INFORMATION GAMES

When all information including the players, their objective functions, and corresponding probability distribution regarding a game are known to all players it is called a non-cooperative game with complete information. otherwise, the game is called an incomplete information game. An incomplete information game is also known as the Bayesian game [281]. A Bayesian game consists of a set of players, a set of actions, types of players, a payoff function for each player, and probability distributions associated with the types. The solution of a Bayesian game is the Bayesian Nash equilibrium. A non-cooperative game reaches its Bayesian Nash equilibrium when each player chooses a strategy that maximizes the expected payoff considering the types and strategies of other players [282].

#### 5) PERFECT INFORMATION AND IMPERFECT INFORMATION GAMES

Games with perfect information are associated with sequential non-cooperative games, in which all players know what actions are chosen by all other players in the past. It is important to note that only in sequential games players can have perfect information. It is important to note that perfect information is different from complete information. In a complete information game, every player knows the strategies and payoffs of the other players but they may not necessarily be aware of the actions taken by other players [283]. These types of games where players do not have perfect information about other players within the game are referred to as imperfect information games.

#### 6) STATIC AND DYNAMIC GAMES

In the static game, players concurrently choose their strategies without having any information about each others' action plans. In dynamic games, however, players can choose their strategies more than once and during the decision-making process, each player can know about the previous strategies of other players. A branch of the dynamic game is the repeated games in which a fixed strategy game is played periodically [283]. In repeated games, before choosing a strategy at the beginning of each period, a player observes the decisions made by other players in previous periods and then decides his current strategy accordingly.

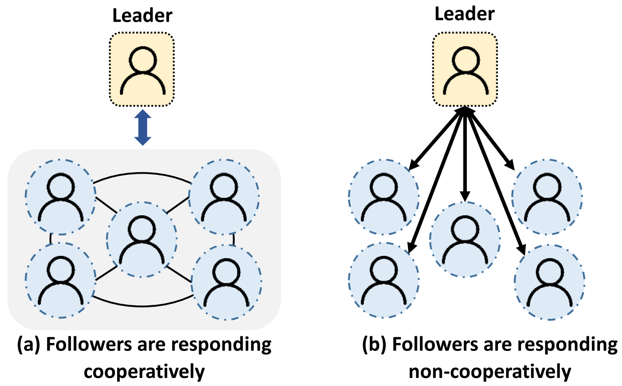


**FIGURE 8. In this figure, we illustrate an example of how a Stackelberg game can be used as both cooperative and non-cooperative games depending on how different players interact and respond. In (a), all followers of the Stackelberg game collectively choose their strategies to respond to the leader of the game. Hence, this game refers to a cooperative Stackelberg game. In (b), however, each player independently responds to the decision made by the leader without collaborating with other players in the network. Hence, this game is a non-cooperative Stackelberg game.**

### C. HYBRID GAMES

A hybrid game can be either a cooperative or a non-cooperative game depending on how players are interacting with one another to optimize their decisions. For example, a Stackelberg game [284], also known as leader-follower game [285], can be considered as both non-cooperative and cooperative game based on followers' modes of interactions in response to leaders strategy. In [286], for example, the authors proposed a non-cooperative Stackelberg game in which followers of the game interact with one another non-cooperatively in response to the leader's decision and reach a Nash equilibrium. Meanwhile, the authors in [22] approached the Stackelberg game as a cooperative game in which followers respond to the leader by forming a coalition with one another using a coalition formation framework to achieve their desired objectives. A demonstration of the Stackelberg game in both cooperative and non-cooperative modes is shown in Fig. 8. Thus, the Stackelberg game and other games that follow a similar phenomenon in articulating players' strategy can be considered as hybrid games.

## IV. GAME-THEORY FOR CYBER-PHYSICAL SYSTEMS

In CPS, due to high engagement between different components for making decisions based on real-time monitoring and control, and the criticality of adaptive control and predictive maintenance for the system's operation, make game theory an ideal candidate to model the users' behavior within a CPS and capture their activities to achieve certain objectives. As such, what follows is an overview of how game theory has been extensively applied in different domains of CPS in the last decade. Further, the summary of the discussion is given in Table 2 and 3.

#### 1) APPLICATION IN GREEN BUILDINGS

In green buildings, the physical system consists of the structure of the building, appliances (HVAC, lights, washing machines, hot water systems, and refrigerators, etc) within the building, and other equipment such as solar panels and batteries. Smart appliances are connected together through various communication protocols through which they can communicate with each other and with the home automation system in real-time within the building. Through artificial intelligence, and machine learning techniques, the home automation system can extract useful information from various sub-systems of the buildings and analyze them in its digital twin where various game theoretic techniques can be used to make useful decisions on energy usage, cost of living, thermal comfort, home security, users' privacy, and resource management and sharing. Thus, as a CPS, green buildings have all the attributes explained in Section II-B that enable game theory to be used to tackle several challenges of design and construction of the building, energy and comfort management within buildings, and sharing resources between buildings while maintaining security and privacy.

##### *a: CONSTRUCTION & INCENTIVES*

To better promote green building constructions, government incentives are widely adopted across the world. Game theory has been used to design the government's reward and penalty evaluations to better promote green building development projects. For example, [287] developed a prospect theory-based evolutionary game model to investigate a suitable strategy for promoting green building construction using four scenarios and determined dynamic reward and static penalty as the best strategy. While government incentives are important, real-state developers need to comply with government regulations to come forward to construct green buildings. Through an evolutionary game framework, the authors in [288] showed that strong government regulations could be inefficient in motivating developers to achieve target green constructions, and therefore a balance needs to be achieved between regulation and builders' own philosophy for encouraging sustainable building design [289]. It is also important to manage conflicts in the construction contract, e.g. using game theoretic models [290], [291] while conforming to the architectural design [292] and understand occupants viewpoint about dwelling in green buildings [293] for better social acceptance.

##### *b: ENERGY USAGE & COMFORT*

The importance of game theory is also evident in modeling the synergy between different appliances in managing energy usage and comfort within buildings. For example, the main sources of energy usage in buildings are HVAC, lighting, and hot water systems. Fortunately, these are also flexible loads that open opportunities for energy conservation. However, for saving energy and efficient building operation, it is important to opportunistically control and optimize these appliances as well as perform necessary predictive maintenance. In [294], game theory is used with reinforcement learning to develop a technique that can determine suitable settings for a building's HVAC system by updating and enhancing its knowledge about the best action for HVAC control under different conditions from historic information about weather conditions, the stochastic nature of the power grid operation, and human activities. A game-theoretic demand-side management technique for buildings is studied in [295] to reduce the peak-to-average ratio of a community in Sydney. The authors in [296] considered three scenarios based on occupancy within a building and showed that game theory can be effectively used to model the decision-making process of building owners and residents about participating in green retrofit projects. Further, a non-cooperative Stackelberg game that uses different discomfort and interruption indicators for controlling residential air-conditioning systems is proposed in [297] to reduce the electricity cost to the customers and maintain their thermal comfort.

##### *c: ENERGY SHARING*

Besides individual energy and thermal comfort management capability, another unique characteristic of modern buildings is the ability to communicate with one another for sharing resources [121]. The research in this area of research is diverse and substantial. For example, in [298], [299], [300], and [301], the foci of the research have been to design game-theoretic algorithms that will enable multiple green buildings within a community to share common resources such as renewable energy [298], [299] and battery capacity [300], [301] with one another to reach a solution that is beneficial in terms of improving sustainability and reducing the cost to all participating buildings.

##### *d: CYBER SECURITY*

Green buildings are prone to cyber-attacks. Hence, maintaining cyber security in green buildings is very important and game theory has been proven to be a useful tool for that purpose [302]. In particular, green buildings are equipped with wireless networks and IoT that are vulnerable to cyber-attacks. As such, a zero-sum game model is built in [303] to control the attack and enable the defense mechanism to realize secured transmission of information from sensors to the controllers. A similar application of game theory for CPS security can also be found in [304]. Nonetheless, to attack a building or similar CPS and achieve the desired physical disruptions in its operation requires the attacker a good understanding of the failure conditions of the system and its control principles. Therefore, to build a robust security system for a building, consideration of such issues is important. Meanwhile, it is also important to make a balance between the security of a building and the cost of implementing those security measures. A game theory-based method is modeled in [305] that considers the failure conditions of the system and its control principles while implementing the security measures. Further, defense mechanism policies against different types of attacks using a hybrid-stochastic game are proposed in [306] that balances the security overhead and control cost. Through game theory, green buildings also contribute to improving the energy efficiency of the modern smart grid by providing various energy management services as active prosumers.

#### 2) APPLICATION IN SMART GRID

In the smart grid, resources used for the generation, transmission, and distribution of electricity, buildings, electric vehicles, and battery storage can be thought of as the physical systems of the CPS. These resources are mostly interconnected and can communicate with one another to make intelligent decisions [128] in order to attain individual objectives [273]. The decisions are taken in cyberspace, e.g., via game theory and distributed leader technology [307] using data-driven techniques based on big data from different subsystems. Different computational intelligence techniques are utilized for the decision-making process [308] and cloud-based information processing makes the decision-making faster and scalable [48]. Smart grid attributes such as IoT enable the controller to sense any changes in the environmental settings and access the internet of information to make predictive decisions about various parameters for adaptive control of the activities of various components within the system. Security and privacy are of paramount importance in a smart grid where real-time monitoring and control are strictly used for energy and thermal comfort management without compromising the privacy and security of the people. Users can actively participate in energy management through human-machine interaction and can influence the overall energy system behavior through social platforms [309]. The practice of game theory is extensive in the smart grid. Beginning from designing demand response management schemes, game theory finds its applications in developing transactive energy frameworks, implementing peer-to-peer energy sharing schemes, designing real-time pricing and incentive mechanisms, managing energy in microgrids, and providing solutions to maintain power system security and stability.

##### *a: DEMAND RESPONSE*

Demand response can be defined as the voluntary reduction or schedule of electricity use by customers with the purpose to keep the electricity grid stable by maintaining the balance between demand and supply of electricity. Direct involvement of customers in demand response makes game theory a perfect candidate to model the voluntary change in energy usage behavior by the people [310]. Now, demand response can be done either via direct control of customers' load by the electricity operator [126] or through providing incentives to the customers through a real-time pricing scheme as explained in [311], [312], and [313]. In the direct control demand response scheme proposed in [126], the purpose of using a cooperative game is to minimize the cost of forming unions of multiple users and single retailer that enable residents to indirectly access the balancing market to reduce the risks and costs for the retailer. In indirect control, on the contrary, the use of game theory helps to optimize the scheduling of flexible loads [98], develop suitable incentives through dynamic pricing scheme [311], [312], and engage extensive customers participation in demand response [314]. Another alternative of demand response technique - known as negawatt [315] - has emerged recently and a cooperative game-based negawatt management is proposed in [316] to demonstrate how negawatt trading can bring financial benefits to the participating customers without any negative impact on the physical distribution network.

##### *b: TRANSACTIVE ENERGY*

Transactive energy and peer-to-peer energy sharing are the other two branches of the smart grid that have broad applications of game theory. Transactive energy uses economic and control techniques to manage the flow of energy within a power system. On the other hand, peer-to-peer energy sharing is a part of a transactive energy mechanism that helps prosumers in a community to share their surplus with other peers at a price negotiated by themselves. In both cases, prosumers' flexibility in changing their energy usage behavior plays an important role where game theory has been used extensively. For example, a nucleolus-based cooperative game solution is proposed in [317] that utilized the flexible loads of prosumers and considers the uncertainties of renewable energy resources to manage energy in local communities. A Stackelberg game is used to develop a joint energy and reserve dispatch model in [318] to ensure the reliability of system operation under renewable energy uncertainty. To maximize the benefit of distributed energy resources for flexible prosumers in terms of procuring revenues by trading electricity in the market, the authors in [319] and [320] explore algorithmic and non-cooperative games respectively to realize suitable transactive energy frameworks. Other aspects of transactive energy and peer-to-peer sharing, in which game theory has been used extensively include regulation services [321], balancing supply and demand [322], reducing electricity cost [323], [324], peak load reduction [22], encouraging customer participation [325], security of energy transactions [326], and privacy-preserved energy trading for neighborhood area networks [327].

##### *c: PRICING*

Both demand response and transactive energy services necessitate the active participation of prosumers. A key incentive to motivate prosumers actively participate in energy management is an attractive pricing scheme. Consequently. designing new and fair pricing schemes has been a core focus of smart grid research for a long time using game theory due to its inherent ability to capture people's rational behavior. For example, to assist the grid, a dynamic pricing profile using a non-cooperative game is proposed in [328] to engage prosumers to address the duck curve problem. With a similar purpose of helping the grid, a game theory-based dynamic pricing strategy is studied in [311] that not only achieves significant peak load reduction but also enables participating prosumers to achieve noticeable profits for participating in the demand response program. Similar dynamic pricing-based demand response programs can also be found in [312] and [329] that use Stackelberg game, and [330], [331] using non-cooperative Nash game.

##### d: MICROGRID MANAGEMENT

Another aspect of smart grids that finds considerable use of game theory is microgrid management including energy trading between microgrids and designing energy management services within a microgrid. In terms of energy trading, games that have been used include Stackelberg game [17], non-cooperative Nash game [332], multi-level interactive game models [333], Bayesian game [334], and cooperative game theory [335], [336]. For managing energy within microgrids, on the other hand, hierarchical decision-making processes are modeled in [337] and [338] using Stackelberg game theory for maximizing profits for different stakeholders within a microgrid including users, microgrid controller, and microgrid aggregators. For optimal dispatch of power within a microgrid, an evolutionary game is used in [339], whereas the authors in [340] use a population game for distributed control of microgrid with the same purpose of dispatching active and reactive powers. Finally, non-cooperative games are used in [341] and [342] for managing energy within microgrids considering the intermittent nature of renewable energy generation.

#### 3) APPLICATION IN INTELLIGENT TRANSPORTATION SYSTEMS

As IoT and emerging computational techniques are revolutionizing the emerging technological realm, transportation networks and vehicles within the network are becoming smarter day by day. Innovation in personalized electric cars, heavy automotive vehicles, roadside real-time communication and monitoring devices, and intelligent transportation systems are contributing to moving people across the globe through safe, hassle-free, cost-effective, and efficient mobility options. Using real-time information on traffic conditions, weather and historic information of the driver's driving patterns, the cyber unit of each vehicle is able to use game theory to calculate the safest and fastest route to its destination and adaptively change the routes as the data shows changes in the circumstance. For that purpose, all components of the intelligent transportation system need to be interconnected with one another through a smart communication system such as 5G, human need to interact with the vehicle directly, and each component of the CPS should have its own control unit to execute the action plan decided by its cyber unit in real-time. In particular, game theory has been heavily used for vehicle-to-vehicle (V2V) [343] and vehicle-to-grid (V2G) [344] technologies for coordinating energy charging, discharging, and transferring of energy by different stakeholders. In V2V, for example, applications of game theory can be found in modeling electricity trading between electric vehicles [345] using a Bayesian game; autonomous V2V decision making in the roundabout using prisoner's dilemma [346]; modeling lane-changing behavior of drivers using two-person non-zero sum game [347] with both complete and incomplete information; enabling longitudinal autonomous driving through Nash differential game [348], and allowing vehicles to offload their computation-intensive tasks to neighboring vehicles using Stackelberg game [349].

##### a: INTELLIGENT DRIVING

Intelligent transportation system has other beneficial and intelligent attributes including autonomous driving capability, safe driving experience through real-time information processing, and cost savings through opportunistic use of its fuel. In [350], for example, the authors present a game theoretic traffic model that can be utilized to test and compare various autonomous vehicle decisions and control systems. To avoid unintentional congestion in data communication among autonomous vehicles, a bimatrix game is proposed in [351], which can effectively solve the performance bottleneck and optimize the process of communication. Similarly, a Nash differential game is used to address longitudinal autonomous driving for intelligent hybrid electric vehicles that ensures the safety, economy, and comfort of the riders are optimized.

##### b: MONITORING & CONTROL

However, such autonomous driving of vehicles relies on the real-time monitoring and accurate control of traffic conditions on road including vehicles and pedestrians. For example, with IoT and intersection controllers in place, traffic control in intersections can be managed properly through a cooperative game-enabled mechanism [352]. It is also possible to accurately manage the change of lane by autonomous vehicles on roads through stochastic game [353]. Vehicles can also interact with pedestrians for their safe navigation through the road, as proposed in [354] using an empirical game theory.

##### c: ENERGY SERVICE

V2G, on the contrary, is being used for providing regulation services to the grid, coordinated scheduling of charging and discharging of electric cars, facilitating peer-to-peer energy sharing within communities, planning for future smart cities, and demand response management purposes. For instance, a non-cooperative Stackelberg game and a potential game are formulated in [344] to motivate electric vehicles to provide frequency regulation services to the power grid. Meanwhile, game theory is utilized in [355] to provide voltage regulation services to the grid. Topics on coordinated scheduling of charging and discharging of electric vehicles are studied in [356], [357], [358], and [273] using Stackelberg and coalition games, while it is shown in [359] and [360] that different game theoretic approaches also have the capacity to enable electric vehicles to participate in peer-to-peer energy sharing. Other applications of V2G for providing energy services can be found in [361] and [362]. We further find the use of different games in the context of V2G in infrastructure planning projects for charging and discharging in smart cities [357], [363] and demand response management using electric vehicles [364], [365].

#### 4) APPLICATION IN TELE-MEDICAL SYSTEMS

In a tele-medical system, the physical system includes the hospitals with a patient monitoring unit, tele-consultation interface, and sensory units consisting of an ECG sensor, medical super sensor, motion sensor, and EMG sensor. The data collected by these sensors are transferred through a wireless local area network (WLAN) to a collector where the data is converted into useful information. This information is processed in the cloud-based medical server from where doctors can access the data and remotely help the patient in real time. The details of the architecture of tele-medical system can be found in [366]. The key attributes of tele-medical systems include real-time monitoring and control, the use of IoT to enable data-driven decision-making, human-machine interaction, maintaining the security of the interconnected system, and preserving the privacy of patient information. The use of game theory in tele-medical CPS stems from their applications in diagnosis and treatment. In particular, game theory has been used for building efficient healthcare IoT, optimizing the diagnosis and treatment process, and building trust between doctors and patients.

##### *a: EMERGENCY SERVICE*

In critical medical emergency situations, for example, health monitoring systems in wireless body area networks need to send data packets with critical health information with less processing time than regular health care information. In [367], the authors demonstrate that evolutionary games can accelerate the process of critical data transfer in a priority-based time-slotted fashion. The importance of low latency data transmission is also recognized in [368], which focuses on fog-based Internet-of-Health Things and proposes a weighted majority game theoretic approach for selecting fog devices in indoor and outdoor regions for delay-sensitive health care system. A similar application of game theory in health care IoT can also be found in [369].

##### *b: DIAGNOSIS & TREATMENT*

Game theory has also been proven very effective in optimizing the diagnosis and treatment process of different diseases. In [370], for example, the authors explore game theory to develop a model the liver transplantation consultation for patients who suffer from Alcoholic Liver Disease. To enable privacy-aware medical imaging for patients' treatments, a novel encryption method is proposed in [371] using Nash bargaining. Another image processing technique is proposed in [372] that uses a game theory-based meta-heuristic FIR filter to compress the medical image for online use. A cooperative game-based leukemia classification approach is proposed in [373] using a data set containing 400 samples of human leukemic bone marrow. A cooperative Bayesian game model is proposed in [374] to analyze the benefit of relying on a clinical decision support system for the overall reputation of a health facility. In [375], the authors model cancer treatment as a game and use an evolutionary game theoretic approach to decide the optimal amount of drug for chemotherapy. A review of studies that discuss how game theory has been used for cancer treatment can be found in [376].

##### *c: TRUST MANAGEMENT*

Game theory also has a notable application in building trust between patients and healthcare systems. In particular, with the advancement of artificial intelligence in the health care system, the trust issue in medical consultation has become a concern for patients [377]. In [378], the authors use game theory to analyze and discuss how to establish continuity and trust in primary health care. And to build this trust, it is important that have a positive public opinion about the doctor-patient relationship. For that purpose, a tripartite evolutionary game is studied in [379] to examine the behavioral strategies of doctors, governments, and netizens, and analyze their impacts on the evolution of public opinion on the doctor-patient relationship. Finally, it is concluded in [380] that medical CPS is a disruptive approach to enable smart healthcare; however, the security and privacy of medical devices and low latency interoperability between them is critical for their sustainable operation in the diagnosis and treatment of diseases. Game theory can play a big role in that purpose as shown in [381] and [382] respectively.

##### *d: OTHER APPLICATIONS*

Another game-theoretic application in medical CPS can be found in analyzing the medical disputes among different levels of medical institutions [383], capturing strategic behavior of surgeons in operating rooms [384], quality maintenance of hospital medical equipment and pharmaceutical products [385], optimal scheduling of ambulance dispatching [386], sharing of resources (doctors) among hospitals [387], medical waste recycling and transportation [388], and for solving congestion in the plastic and reconstructive surgery match [389].

#### 5) APPLICATION IN AUTONOMOUS ROBOTIC SYSTEMS (UAV/UGV)

For autonomous robotic systems including UAV and UGV, it is imperative for agents to interact with one another and

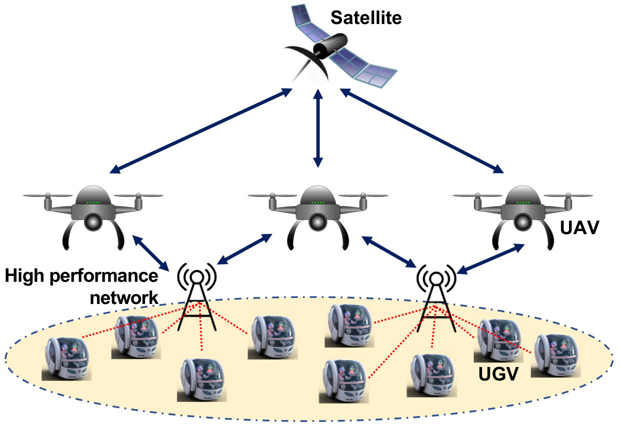


**FIGURE 9.** This figure shows how multiple UAVs can coordinate with one another to provide a platform for communications between UGVs to operate on the ground. This figure is inspired by the discussion in [391].

with other entities of the environment with delay tolerant and efficient communication protocols for accurate routing, localization, and completing the target actions. Therefore, the physical architecture of the UAV and UGV consists of a central processing unit that controls the flight (or routing) of the UAV (or UGV). There is a ground control station that provides the human controller with facilities to access the control of the UAV/UGV during operation. Smart communication between the physical units and UAV/UGV is used for transferring the control signal from the station to the vehicles. The central processing unit analyzes the environmental data obtained from the UAV/UGV in real-time and process the data to generate secured control commands to feedback to the vehicles for execution. Thus, adaptive control, real-time monitoring and control, data-driven adaptive control, and security are the main attributes for the successful operation of UAV and UGV systems. For details, please see [390]. In this domain, game theory has been used for modeling the decision-making of and interaction between agents. In this domain of CPS, game theory has been extensively used to (1) decide the optimal placement of UAV, (2) coordinate and control UAV and UGV, (3) save energy and power, and (4) ensure security.

*a: COMMUNICATION SERVICES*

For providing communication services to the UGV on the ground, the UAV height has an impact on the service quality and coverage. It is important that they are positioned appropriately so that the number of UAV deployments can be reduced significantly to provide the desired network services. In [392], a non-cooperative game is used to find the optimal locations of UAVs for providing communication services, e.g., to a group of UGVs operating on the ground. In [393], the authors study the routing problem for multi-agent UAVs using game theory where a set of UAVs collect information via surveillance of an area of interest without relying on a reliable communication medium to coordinate with other UAVs. Similarly, in [394], an artificial intelligence-based game theoretic approach is proposed for UAVs to control their flight algorithms to position themselves in suitable locations to maintain strong connectivity. Details of how joint coverage and connectivity for distributed UAV networks can be facilitated via game theory are detailed in [395] and [391]. Note that the communication platform provided by UAVs enables the coordination and control of both UAVs and UGVs, as shown in Fig. 9.

*b: SURVEILLANCE*

Coordination between UAVs and UGVs using their real-time spatial and temporal locations and electromagnetic information is important for their path planning and obtaining intended objectives with the desired efficiency. For example, in [396], a game theory-based optimization technique is proposed for path planning for multiple UAVs to improve the mission efficiency and range. A similar approach is used for recurring scenarios in [397], in which the coordination among robots with shared objectives are analyzed using a potential game. The alliance between UAV and UGV is studied in [398] for cooperative surveillance using a co-evolutionary algorithm that prioritizes early detection and improves the success rate. A dynamic multi-team antagonistic game is proposed in [399] for multiple UAVs to solve problems of tactical decision-making with incomplete information. Other examples of game theoretic coordination of UAV and UGV can be found in [400] and [401].

*c: ENERGY EFFICIENCY*

Most of the unmanned vehicles are deployed in areas that are not easily accessible by humans due to either locational hazards (e.g., mountains and forests) or security threats (e.g., battlefield). As a consequence, frequent replacement of the batteries of the robots is not feasible. Hence, it is important to optimize the operation and maintenance of UAV and UGV for efficient and opportunistic use of energy. In fact, UAV cooperative control has been used in many UAV communication networks such as in [402] where a potential game is used for the purpose of power control. For the purpose of increased battery life, delay-aware and energy-efficient task management techniques for IoT platforms for UAV and UGV are studied in [401], [403], [404], and [405] that use joint-auction coalition game, non-cooperative game, coalition formation game, and non-cooperative matching game with no-regret learning respectively to develop the mechanisms. Further discussion on how game theory can be used to ensure energy-efficient activities of UAV and UGV can be found in [406].

*d: SECURITY*

In autonomous robotic CPS, game theory has also been utilized extensively for modeling and analyzing the cyber-physical security of time and location-critical UAV and UGV applications. One general way to design such game theoretic formulation is to model the interaction between a UAV (or UGV) operator and an interdictor where each of them could be benign or malicious [407]. The solution of the game is then analytically studied to understand its effects on the rationality and strategies of both parties and find the equilibrium points under different selected security regimes. A dynamic game approach for preparing a secured and resilient networked system is proposed in [408] and demonstrates its effectiveness for a UAV network. For securing transmission in a two-tier UAV network, a two-level game based on a many-to-one matching game and a coalition formation game is implemented in [409] that guarantees the desired secrecy performance of the system. UGV in the defense force sometimes faces the threat of intelligent autonomous adversaries to disrupt the transfer of resources [410], e.g., by manipulating the signals in the GPS. To address this challenge, a Stackelberg game-theoretic countermeasure is proposed in [411] to develop new security solutions against the such attack and tested on UAV networks. Another example of game theoretic application in a similar domain can be found in [412] that uses an interdependence-aware game-theoretic framework for compensating the power losses that could cause due to an attack by the malicious agents within the network.

### 6) APPLICATION IN SMART CITIES

A smart city, as depicted in Fig. 6, is a platform that integrates different types of CPS together to efficiently manage assets, resources, and services within urban areas to improve its overall city operations. Thus, the architecture of a smart city is alike to the one shown in Fig. 1 with all attributes outlined in Section II-B. The smart city architecture and attributes enable the collection and flow of data across different CPS, and then process and analyze the information for monitoring and managing power plants, traffic and transportation systems, water supply systems, waste management systems, health systems, community service systems, and maintaining the security of the citizen. Due to the scale of operation in a smart city, the management of data is challenging, and game theory has been proven to be very effective. In [413], for example, a Stackelberg game is utilized to design an intelligent edge computing algorithm that can alleviate the huge computing pressure from smart cities as the number of data increases day by day. Another game theory-based edge computing technique is proposed in [414]. In particular, an evolutionary game is used to qualitatively study the validity and stability of the trust management mechanism for smart cities. While most of the smart city activities have been explained as part of different CPS in this paper, waste management and security surveillance are exclusively relevant to the smart city.

#### *a: WASTE MANAGEMENT*

The seamless flow of data across different agents within the smart city enable game theory to contribute to waste management systems. For example, In [415], the authors identify the decision behaviors of contractors using an evolutionary game for better construction and demolition of waste management. In particular, the authors discuss how the decision of contractors can be influenced in different circumstances and identify the main factors that have impacts on their decision-making process. For example, it is shown that supervisory intensity, supervision costs, penalties, waste disposal costs, and revenues from illegal dumping are the major element that regulates government and contractors' initiative regarding waste management. In [416], the authors propose a technique that can help analyze different express packaging waste recycling models for smart cities. With the purpose to contribute to designing effective incentive measures and recycling models, this work uses a differential game to understand the behavioral characteristics of individuals and different types of recycling models. It is identified that a cooperation-driven recycling model can have the highest revenue and subsidies are necessary for improving recycling in the smart city.

#### *b: SECURITY*

Security is another crucial component for the smart city considering its reliance on data-driven infrastructures [417]. In terms of maintaining privacy and security in the smart city, game theory has been used for ensuring the security of critical infrastructures like smart grids [418], gas and water systems [419], traffic systems [412], and IoT [420]. In [418], a dynamic multi-stage game is developed using reinforcement learning to identify the optimal attack sequences for given objectives to help to improve the security of the system. A non-zero-sum game is proposed in [419] which identifies that the interdependence of power systems on natural gas and water systems of the city may influence attackers to target water and gas systems for a cyber attack. Therefore, appropriate security measures need to be taken for these critical infrastructures as well. In [412], a Stackelberg game is used to optimally allocate the backup power sources for base stations to ensure uninterrupted services to power and transportation sectors of the smart city in case there is a power interruption due to a cyber attack in the smart grid. Finally, a repeated game-based enhanced clustered WSNs-based IoT security is proposed in [420] to combat selective forwarding attacks and thus preserve network stability. A detailed overview of the importance of game theory for cyber security can be found in [421].

### 7) APPLICATION IN SMART AGRICULTURAL SYSTEMS

Smart agricultural system consists of a sensor layer, which can be thought of as the physical system of the CPS. This layer includes various kinds of crop sensors and smart objects responsible for real-time data collection and monitoring. Occasionally, thermal drones may also be used for detecting heat from objects and materials used for agricultural purposes. The smart connection between different components is provided by the network layer with communication technologies available between sensors and the Internet. The IoT platform utilizes a wireless sensor network for large-area surveillance and helps the farmer to maintain the optimal condition for maximum productivity. The service layer of the smart agricultural system serves as the cyber and cognition levels of the CPS. This layer is responsible for the processing and analysis of collected data for taking optimal decisions about agricultural plans. The data processing unit and decision support system of the service layer manage the collected information from the fields and take decisions for optimal crop yield, resource savings, and quality assurance. Finally, the application layer mimics the configuration level which enables farmers to take necessary actions by providing visualization of information and suggesting different kinds of field optimization deployments including irrigation, pesticide drift control, cultivation process, and crop disease protection. Further details of the architecture can be found in [422]. Considering the applications of different layers, the main attributes of a smart agricultural system include adaptive control, IoT, real-time monitoring and control, interconnectivity, predictive maintenance, and human-machine interaction, which make game theory a suitable tool to apply for modeling smart agricultural activities. The Exploration of game theory for innovative agricultural practice is diverse - starting from the selection of agricultural crops as proposed in [423] in 1962 to today's challenge of water allocation for agriculture purposes [424]. For the agricultural CPS, in particular, game theory finds its main applications in two areas: smart farming and water management.

#### *a: SMART FARMING*

In smart farming, farmers have better control over the cultivation process including animal husbandry, crop diseases, pest control, moisture control, and weather prediction through real-time monitoring of crops, an inspection of irrigation equipment, and predictive maintenance of the crops and field as required. Game theory has been used considerably for these purposes. In [425], for example, a smart farming technique is proposed using a cooperative game that enforce farms to cooperate together for better performance and solving problems with defective farms. A perfect information non-cooperative game with a hierarchical structure is developed in [426] to demonstrate how the production efficiency of multiple farms can be affected if some farms may choose to deviate from their strategies after the game reach a Nash equilibrium. Blockchain-based trust management for agricultural green supply is designed in [427], in which the authors use a Bayesian game to ensure the data reliability provided by different sensors. For agricultural land fragmentation, a non-cooperative game is proposed in [428] to establish the finding that if a government wants to manage agricultural land fragmentation, similar strategies should not be chosen for all agricultural lands. Finally, how grain production management can be used to reduce global warming under financial constraints and the time value of money is studied in [429]. In particular, the authors developed an evolutionary game to evaluate the performance of financially constrained producers when they adopt a sustainability strategy while considering the government's long-term cap-and-trade regulation.

#### *b: WATER MANAGEMENT*

Another important attribute of agriculture is the water management system. In fact, agriculture is the largest consumer of water [430], and a water management system is responsible for administering water across different lands or scheduling the flow of water for the same land for irrigation purposes. Sharing a body of water for agricultural practices raised conflicts between farmers for centuries, some of which have been captured in game theory for developing water management solutions. Several kinds of literature in the eighties and nineties addressed various water management problems among different farms. For example, the authors in [431] suggest an oligopoly model to set the definition of the equilibrium on water volume to find a solution to the irrigation problem. In [432], the problem of pumping water from a common aquifer is modeled using differential open loop and feedback games. It is demonstrated that dynamic inefficiency increases as more landowners have access to the aquifer. Combining game theory with policy analysis, the authors in [433] investigate how irrigation institutes influence the distribution of equilibrium outcomes of irrigators. Today, the management of water for irrigation still remains a challenge as part of the smart agricultural CPS. In [434], Wald's maximin model of game theory is used for modeling the decision-making process in farming irrigation systems considering uncertainties. A Bayesian game theory is used in [435] to develop an intelligent IoT irrigation system that carries out cruise irrigation based on humidity information and a path planning algorithm. Finally, a detailed discussion on farmers' cooperation in participatory irrigation is given in [436], in which game theory is used to identify that local funds may incentivize farmers to cooperate together to make participatory irrigation sustainable.

### 8) APPLICATION IN INDUSTRY 4.0

According to [437], the architecture of Industry 4.0 consists of all levels depicted in Fig. 1 and subsequently possesses all desired attributes articulated in Section II-B. As a result, as other CPS discussed in this paper, the game theory also has increased applications in the area of manufacturing - in particular for quality assurance, sustainable manufacturing, and production certainty in Industry 4.0.

#### *a: QUALITY ASSURANCE*

Irrespective of the product type - whether the plant is for the healthcare service or food quality assessment, for example - game theory has found its application in all sectors of manufacturing. In healthcare service, for instance, an equilibrial service composition model in cloud manufacturing is proposed in [438]. In the proposed model, both cooperative and non-cooperative games are used to model the interaction between manufacturing cloud service providers and consumers to ensure improved quality of services based on consumers' needs. In the sports industry, game theory is used in [439] to provide efficient services in the sports arena. In particular, a two-player game-based model is formulated for efficient decision-making by monitoring officials utilizing IoT-based data on athletes' performance. For smart food quality assessment, a game theory-based framework is established by [440]. In the framework, a Bayesian game is explored to develop a computing platform for quantifying the probability of food quality using IoT-based data from restaurants and food hubs.

#### b: SUSTAINABLE MANUFACTURING

In the fashion industry, shoes and clothes are being shifted towards sustainable manufacturing - the culture of *throwing away products* is replaced by *responsible consumerism*. However, this practice is yet to be adopted by the manufacturing farms with large-market shares. In [441], the authors have discussed how different types of game models can effectively capture the engagement of different stakeholders to practice sustainable product usage and how that can impact the apparel industry. Evolutionary game theory is being used in [442] and [443] to understand how the Government's regulation and enterprise decisions can affect the manufacturing industry and select the green and low-carbon innovation in manufacturing enterprises.

#### c: PRODUCTION CERTAINTY & OTHERS

To reduce the supply chain risk and uncertainties of producing customized products, a three-level game theoretic model is proposed in [444] in the area of crowd-sourced manufacturing. This study models interactive decisions that determine the optimal solutions for a single manufacturer, multiple distributors, and multiple subcontractors by confirming that all stakeholders' profits are maximized. Among other manufacturing industries, the use of game theory can be found in cellular manufacturing systems (using a cooperative game [445]), cloud manufacturing (using a minority game [446]), vaccine manufacturing (using an evolutionary game [447]), warehousing industry (using a cooperative game [448]), and prefabricated building project (using an extensive form game [292]).

## V. PROPOSALS FOR FUTURE RESEARCH

Based on the discussion in this paper, it is clear that the properties of CPS and how different types of CPS are contributing to changing our lives are well demonstrated in the existing literature. On the one hand, CPS like telemedicine systems, smart grids, smart agricultural systems, and autonomous robots offer facilities including emergency diagnosis and treatments, electricity, sustainable food supply, and defense against the enemies that are critical for our survival. On the other hand, the amenities and convenience offered by green buildings, intelligent transportation systems, industry 4.0, and smart cities make our lives spontaneously easy and rewarding.

We have seen in our discussion - also summarized in Table 1 - that the characteristics of CPS are well aligned with the properties of multi-agent systems. Therefore, the usefulness of outcomes of various CPS is contingent on the interaction between different agents and their interactive decision-making models. Given this context, game theory has found profound applications in CPS research and has been used extensively in the literature - as compiled in Table 2 and Table 3 - to address miscellaneous decision-making and control challenges. However, albeit the contribution of game theory in the CPS research to date is voluminous, there are a number of potential challenges that are yet to solve - particularly lying in innovative ways to merge the roles of different CPS for the greater good. These challenges are encapsulated in the following discussion.

### A. CONNECTED COMMUNITY

While green buildings are capable of optimally managing their own resources as well as sharing some of their resources with neighboring buildings, how such individual and collective management of resources can be exploited to benefit other CPS needs to be investigated. For example, as buildings are responsible for 60% of total electricity consumption [48], collectively they could be very useful for providing demand flexibility to the grid. However, this would necessitate multiple buildings to cooperate with one another and act as a connected community [121], which is challenging given the fact that building owners are self-interest entities. Game theory could be a potential tool to model such a scenario. For example, either coalition formation or a potential game could be used to encourage coalitions among different green buildings to exploit their elasticity in managing distributed energy resources to provide demand flexibility to the grid.

### B. INTELLIGENT TRANSPORTATION FOR MEDICAL PURPOSES

Emergency response is a crucial part of medical CPS and intelligent management of ambulances is vital for this service. In an emergency, it is not only important that ambulances are dispatched as a priority but also choosing the optimal path to reach the patient at the earliest possible time is also essential. Making ambulances parts of intelligent transportation systems could be one potential solution to increase the efficiency of medical services. In that case, ambulances will be able to interact with other intelligent vehicles on road, information hubs, and satellite navigators to find the optimal route to reach their destination and help save millions of lives. For example, a Stackelberg game [284] can be used to model some scenarios in which ambulances - as part of the intelligent transportation system - will act as the followers of the game to optimize their reaction time and time delay to reach the destination in response to the medical emergency request issued by the medical CPS - modeled as the leader of the game.

**TABLE 2. Summary of applications of game theory in the areas of green buildings, smart grids, intelligent transportation systems, and tele-medical systems.**

| Type of CPS | Research area | Foci of the study | References |
|---|---|---|---|
| Green buildings | Design and construction | Promoting green building construction by incentivizing stakeholders to comply with government regulation by enabling sustainable construction practice. | [287]–[293], [449] |
| | Energy and comfort management | Modeling the synergy between different appliances within buildings for managing energy usage within the buildings while maintaining the comfort of occupants at the desired level. | [294]–[297] |
| | Sharing energy resources | Enabling buildings to share their energy and storage spaces with one another in through secured communication and transactions. | [121], [298]–[306] |
| Smart grid | Demand response | Managing customers' energy generation and demand portfolio via either direct or indirect control of their flexible distributed energy resources. | [98], [126], [311]–[316] |
| | Transactive energy | Using economic and control techniques to manage the flow of energy within a power network | [317]–[320] |
| | Peer-to-peer trading | Helping prosumers in a community to share their surplus with other peers at a price negotiated by themselves. | [22], [321]–[326] |
| | Microgrid management | Developing energy trading between microgrids and designing energy management services within a microgrid. | [17], [332]–[342] |
| | Prosumer engagement | Designing innovative and fair pricing schemes using game theory to capture people's rational behavior. | [311], [312], [328]–[331] |
| Intelligent transportation system | V2V | Modeling of interaction between different EVs for different purposes including electricity trading, lane changing, and coordinated charging and discharging. | [345]–[349] |
| | V2G | Designing regulation services to the grid, coordinating scheduling of charging and discharging of electric cars, facilitating peer-to-peer energy sharing within communities, and planning for future smart cities. | [273], [344], [355]–[357], [357]–[360], [363]–[365] |
| | Intelligent and safe driving | Demonstrating the effectiveness of efficient data communication and information processing for the autonomous and safe driving experience. | [350]–[354], [361], [362] |
| Tele-medical system | Critical response | Accelerating the process of critical data transfer in a priority-based time-slotted fashion and quick response to patients' requests. | [367]–[369] |
| | Diagnosis and treatment | Modeling organ transplantation consultation, privacy-aware medical imaging, and data-driven critical decision support. | [370]–[376] |
| | Trust management | Building trust between the healthcare system and patients by analyzing the impact of behavioral strategies of doctors on the patients. | [377]–[382] |
| | Quality assurance | Capturing strategic behaviors of surgeons in operating rooms and quality maintenance of hospital medical equipment and pharmaceutical products; optimal scheduling of ambulance dispatching and medical waste recycling and transportation | [383]–[386], [388], [389] |

### C. INTERFERENCE IN AUTONOMOUS ROBOTICS SYSTEMS

UAV-based networks are self-organizing networks that are prone to wireless interference. It is expected that a large number of UAVs and UGVs will be deployed for different tasks, which will intensify the challenge. Hence, new techniques will need to be developed to address interference management. One potential way is to use a mean field game to analyze the dynamics of a large number of interacting rational agents (i.e., UAV or UGV). Mean field game has the capacity to capture the stochastic nature of a system, e.g., channel dynamics of UAV-based network in this case, without the need for information exchange during the execution of the algorithm [391]. Therefore, it could be a suitable tool to model interference in UAV-based networks with limited backhaul and fronthaul connectivity.

### D. REINFORCEMENT LEARNING FOR SMART AGRICULTURE

In reinforcement learning-based game theoretic models, an agent automatically learns from its past experience and environment and utilizes the feedback to strategically decide on its action to optimize its objective. Thus, such a technique is very suitable for smart agriculture to reduce the impact of the uncertainty of weather conditions, the pattern of weed attacks on the crop, market volatility, and local demand for food on farming. Further, such a model could also be useful for learning the best way to distribute water among different farms and eventually improve the performance in every session to optimize the use of water.

### E. RESOURCE RECYCLING IN SMART CITIES

As discussed earlier, a smart city could be thought of as a platform in which different types of CPS exist together. While it is a challenging task to maintain all the resources needed by different systems simultaneously, it also opens opportunities to recycle some of the resources within the smart city. For example, if UAVs are primarily used for goods delivery purposes [460], it could be also possible to opportunistically use these UAVs for providing security services to the city [461]. This will not only help the city to save

**TABLE 3.** Summary of applications of game theory in the areas of autonomous robotic systems, smart cities, agricultural systems, and industry 4.0.

| Type of CPS | Research area | Foci of the study | References |
|---|---|---|---|
| Autonomous robotic systems | Placement | Accurately locating UAVs to provide a platform for UGVs and other agents within the system to interact with one another via efficient and fast communication protocols. | [391]–[395] |
| | Coordination | Coordinating between UAVs and UGVs using their real-time spatial and temporal locations and electromagnetic information for path planning applications. | [396]–[401] |
| | Operation & maintenance | Optimizing the operation and maintenance of UAV and UGV for efficient and opportunistic use of energy. | [401]–[406] |
| | Security | Modeling and analyzing the cyber-physical security of time and location critical UAV and UGV applications. | [407]–[412] |
| Smart city | Communication | Ensuring accurate computation and fast communication of data across different subsystems within a smart city while ensuring the authenticity of the collected data. | [413], [414], [450] |
| | Resource management | Using game theory to develop approaches that can monitor and manage transportation, power, and waste for the smart city. | [415], [416], [451]–[455] |
| | Medical services | Ensuring proper medical services to its citizens and simultaneously maintaining the privacy and security of their lives. | [456]–[458] |
| | Cyber security | Utilizing game theory for seamless monitoring, storing, and processing of data from different subsystems of a smart city in a secured fashion and maintaining the privacy of the citizens. | [412], [417]–[421], [459] |
| Smart agricultural systems | Smart farming | Controlling the cultivation process including animal husbandry, crop diseases, pest control, moisture control, and weather prediction efficiently through real-time monitoring of crops, an inspection of irrigation equipment, and predictive maintenance. | [423], [425]–[429] |
| | Water management | Administering water across different lands or scheduling flow of water for the same land for irrigation purposes. | [430]–[436] |
| Industry 4.0 | Quality assurance | Enabling interaction between stakeholders and consumers to ensure the delivery of good quality products and services to the customers. | [438]–[440] |
| | Sustainability | Practicing responsible consumerism by enabling large manufacturing farms to work together. | [441]–[443] |
| | Certainty and others | Reducing the supply chain risk and uncertainties of producing customized products and delivering in the market. Further, game theory has also been used in various industries for ensuring effective manufacturing outputs. | [292], [444]–[448] |

significant costs but also reduce the waste material in the long term for the betterment of the environment. Nonetheless, it is a significant challenge to model the opportunistic use of resources for different purposes, which can be modeled via resource-sharing games like cake-cutting or cooperative games.

### F. KNOWLEDGE-BASED USER MOTIVATION FOR SMART GRID

In the future, prosumers will play a major role in smart grid energy management. Hence, it is important for energy users to learn about the future energy transition and equip themselves with the knowledge and skills that are needed to be a part of this transition. This is mainly because people's perspective about technology and using capability can significantly impact the uptake of a new technology [462], [463]. Therefore, a significant amount of research needs to be devoted to preparing courses and training modules targeting different classes of people to educate them about future energy transition, its importance, and how it is going to impact the environment and people's life in the future.

## VI. CONCLUSION

In this paper, we have provided a summary of the recent advances in game theoretic applications to cyber-physical systems. For that purpose, first, we have introduced different types of cyber-physical systems and discussed the general framework that all cyber-physical systems have in common. Second, background on different types of game theoretic models has been given and popular solution concepts of each type of game have been discussed. Third, the relevance of game-theoretic applications to cyber-physical systems has been identified through a thorough review of cyber-physical systems' properties. Then, we have discussed how diverse game theoretic approaches have been explored to address challenges in different cyber-physical systems followed by a short summary of these approaches. We have also identified a number of important topics to consider for future research.

Due to the importance of this topic in our current data-driven world and the comprehensive provided discussion, discussion, it is hoped that this paper will be useful to both experts and non-experts in developing a greater understanding of the role of game theory in the study of cyber-physical systems, and will serve as an entry point into the subject for those wishing to enter the field.

## REFERENCES


[1] K. Kim and P. R. Kumar, "Cyber-physical systems: A perspective at the centennial," *Proc. IEEE*, vol. 100, pp. 1287–1308, May 2012.

[2] B. J. Krämer, "Evolution of cyber-physical systems: A brief review," in *Applied Cyber-Physical Systems*, S. Suh, U. Tanik, J. Carbone, and A. Eroglu, Eds. New York, NY, USA: Springer, 2014, pp. 1–3, ch. 1.

[3] E. A. Lee, "The past, present and future of cyber-physical systems: A focus on models," *Sensors*, vol. 15, no. 3, pp. 4837–4869, Feb. 2015.

[4] Q. Do, B. Martini, and K.-K. R. Choo, "Cyber-physical systems information gathering: A smart home case study," *Comput. Netw.*, vol. 138, pp. 1–12, Jun. 2018.

[5] S. Kolozali, D. Kuemper, R. Tonjes, M. Bermudez-Edo, N. Farajidavar, P. Barnaghi, F. Gao, M. I. Ali, A. Mileo, M. Fischer, and T. Iggena, "Observing the pulse of a city: A smart city framework for real-time discovery, federation, and aggregation of data streams," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 2651–2668, Apr. 2019.

[6] L. Yu, W. Xie, D. Xie, Y. Zou, D. Zhang, Z. Sun, L. Zhang, Y. Zhang, and T. Jiang, "Deep reinforcement learning for smart home energy management," *IEEE Internet Things J.*, vol. 7, no. 4, pp. 2751–2762, Apr. 2020.

[7] D. J. Cook, G. Duncan, G. Sprint, and R. L. Fritz, "Using smart city technology to make healthcare smarter," *Proc. IEEE*, vol. 106, no. 4, pp. 708–722, Apr. 2018.

[8] L. Zhu, F. R. Yu, Y. Wang, B. Ning, and T. Tang, "Big data analytics in intelligent transportation systems: A survey," *IEEE Trans. Intell. Transp. Syst.*, vol. 20, no. 1, pp. 383–398, Jan. 2019.

[9] K. Huang, L. Shu, K. Li, F. Yang, G. Han, X. Wang, and S. Pearson, "Photovoltaic agricultural Internet of Things towards realizing the next generation of smart farming," *IEEE Access*, vol. 8, pp. 76300–76312, 2020.

[10] K. Hughes, "The future of cloud-based entertainment," *Proc. IEEE*, vol. 100, no. 1, pp. 1391–1394, May 2012.

[11] T. Sanislav, S. Zeadally, and G. D. Mois, "A cloud-integrated, multilayered, agent-based cyber-physical system architecture," *Computer*, vol. 50, no. 4, pp. 27–37, Apr. 2017.

[12] N. Ul Hassan, C. Yuen, and D. Niyato, "Blockchain technologies for smart energy systems: Fundamentals, challenges, and solutions," *IEEE Ind. Electron. Mag.*, vol. 13, no. 4, pp. 106–118, Dec. 2019.

[13] W. Tushar, T. K. Saha, C. Yuen, D. Smith, and H. V. Poor, "Peer-to-peer trading in electricity networks: An overview," *IEEE Trans. Smart Grid*, vol. 11, no. 4, pp. 3185–3200, Jul. 2020.

[14] A. Napoleone, M. Macchi, and A. Pozzetti, "A review on the characteristics of cyber-physical systems for the future smart factories," *J. Manuf. Syst.*, vol. 54, pp. 305–335, Jan. 2020.

[15] D. Şahinel, C. Akpolat, O. C. Görür, F. Sivrikaya, and S. Albayrak, "Human modeling and interaction in cyber-physical systems: A reference framework," *J. Manuf. Syst.*, vol. 59, pp. 367–385, Apr. 2021.

[16] W. Tushar, C. Yuen, H. Mohsenian-Rad, T. Saha, H. V. Poor, and K. L. Wood, "Transforming energy networks via peer-to-peer energy trading: The potential of game-theoretic approaches," *IEEE Signal Process. Mag.*, vol. 35, no. 4, pp. 90–111, Jul. 2018.

[17] A. Paudel, K. Chaudhari, C. Long, and H. B. Gooi, "Peer-to-peer energy trading in a prosumer-based community microgrid: A game-theoretic model," *IEEE Trans. Ind. Electron.*, vol. 66, no. 8, pp. 6087–6097, Aug. 2019.

[18] C. Yi and J. Cai, "A truthful mechanism for scheduling delay-constrained wireless transmissions in IoT-based healthcare networks," *IEEE Trans. Wireless Commun.*, vol. 18, no. 2, pp. 912–925, Feb. 2019.

[19] Y. Li, W. Yang, P. He, C. Chen, and X. Wang, "Design and management of a distributed hybrid energy system through smart contract and blockchain," *Appl. Energy*, vol. 248, pp. 390–405, Aug. 2019.

[20] X. Huang and J. Dong, "Reliable control policy of cyber-physical systems against a class of frequency-constrained sensor and actuator attacks," *IEEE Trans. Cybern.*, vol. 48, no. 12, pp. 3432–3439, Dec. 2018.

[21] H. Xu, Y. Pan, J. Li, L. Nie, and X. Xu, "Activity recognition method for home-based elderly care service based on random forest and activity similarity," *IEEE Access*, vol. 7, pp. 16217–16225, 2019.

[22] W. Tushar, T. K. Saha, C. Yuen, T. Morstyn, Nahid-Al-Masood, H. V. Poor, and R. Bean, "Grid influenced Peer-to-Peer energy trading," *IEEE Trans. Smart Grid*, vol. 11, no. 2, pp. 1407–1418, Mar. 2020.

[23] W. Saad, Z. Han, H. V. Poor, and T. Basar, "Game-theoretic methods for the smart grid: An overview of microgrid systems, demand-side management, and smart grid communications," *IEEE Signal Process. Mag.*, vol. 29, no. 5, pp. 86–105, Sep. 2012.

[24] M. Rabin, "Incorporating fairness into game theory and economics," *Amer. Econ. Rev.*, vol. 83, no. 5, pp. 1281–1302, Dec. 1993.

[25] F. Allen and S. Morris, "Game theory models in finance," in *Game Theory and Business Applications*, K. Chatterjee and W. Samuelson, Eds. Boston, MA, USA: Springer, 2014, pp. 17–41, ch. 2.

[26] R. J. Ormerod, "OR as rational choice: A decision and game theory perspective," *J. Oper. Res. Soc.*, vol. 61, no. 12, pp. 1761–1776, Dec. 2010.

[27] K. Wang, Z. Ouyang, R. Krishnan, L. Shu, and L. He, "A game theory-based energy management system using price elasticity for smart grids," *IEEE Trans. Ind. Informat.*, vol. 11, no. 6, pp. 1607–1616, Dec. 2015.

[28] R. J. Leonard, "From parlor games to social science: Von Neumann, Morgenstern, and the creation of game theory 1928–1944," *J. Econ. Literature*, vol. 33, no. 2, pp. 730–761, Jun. 1995.

[29] S. J. Brams, *Game Theory Politics*. New York, NY, USA: The Free Press, 1975.

[30] C.-P. Fan, "Teaching children cooperation—An application of experimental game theory," *J. Econ. Behav. Org.*, vol. 41, no. 3, pp. 191–209, Mar. 2000.

[31] J. O. G. Haywood, "Military decision and game theory," *J. Oper. Res. Soc. Amer.*, vol. 2, no. 4, pp. 365–462, Nov. 1954.

[32] M. Marzband, M. Javadi, S. A. Pourmousavi, and G. Lightbody, "An advanced retail electricity market for active distribution systems and home microgrid interoperability based on game theory," *Electr. Power Syst. Res.*, vol. 157, pp. 187–199, Apr. 2018.

[33] X. Liu, M. Dong, K. Ota, P. Hung, and A. Liu, "Service pricing decision in cyber-physical systems: Insights from game theory," *IEEE Trans. Services Comput.*, vol. 9, no. 2, pp. 186–198, Mar./Apr. 2016.

[34] V. C. Gungor and F. C. Lambert, "A survey on communication networks for electric system automation," *Comput. Netw.*, vol. 50, pp. 877–897, May 2006.

[35] X. Guan, B. Yang, C. Chen, W. Dai, and Y. Wang, "A comprehensive overview of cyber-physical systems: From perspective of feedback system," *IEEE/CAA J. Automat. Sinica*, vol. 3, no. 1, pp. 1–14, Jan. 2016.

[36] E. Griffor, "Framework for cyber-physical systems: Volume 1, overview," National Inst. Standards Technol., U.S. Dept. Commerce, Gaithersburg, MD, Tech. Rep. 1500-201, Jun. 2017, doi: 10.6028/NIST.SP.1500-201.

[37] B. Yu, J. Zhou, and S. Hu, "Cyber-physical systems: An overview," in *Big Data Analytics for Cyber-Physical Systems*, S. Hu and B. Yu, Eds. Basel, Switzerland: Springer, Cham, 2020, pp. 1–11, ch. 1.

[38] F. Khalid, S. Rehman, and M. Shafique, "Overview of security for smart cyber-physical systems," in *Security of Cyber-Physical Systems*, H. Karimipour, P. Srikantha, H. Farag, and J. Wei-Kocsis, Eds. Basel, Switzerland: Springer, 2020, pp. 5–24, ch. 2.

[39] D. Ding, Q.-L. Han, Y. Xiang, C. Ge, and X.-M. Zhang, "A survey on security control and attack detection for industrial cyber-physical systems," *Neurocomputing*, vol. 275, pp. 1674–1683, Jan. 2018.

[40] A. A. Khalil, J. Franco, I. Parvez, S. Uluagac, and M. A. Rahman, "A literature review on blockchain-enabled security and operation of cyber-physical systems," 2021, *arXiv:2107.07916*.

[41] F. Giaimo, H. Andrade, and C. Berger, "Continuous experimentation and the cyber–physical systems challenge: An overview of the literature and the industrial perspective," *J. Syst. Softw.*, vol. 170, Dec. 2020, Art. no. 110781.

[42] E. A. Lee, "Computing foundations and practice for cyber-physical systems: A preliminary report," Univ. California-Berkeley, Berkeley, CA, USA, Tech. Rep. UCB/EECS-2007-72, May 2007.

[43] J. F. He, "Cyber-physical systems," *Commun. China Comput. Fed.*, vol. 6, no. 1, pp. 25–29, 2010.

[44] G. R. González, M. M. Organero, and C. D. Kloos, "Early infrastructure of an Internet of Things in spaces for learning," in *Proc. 8th IEEE Int. Conf. Adv. Learn. Technol.*, Santander, Spain, Jul. 2008, pp. 381–383.

[45] Y. Liu, Y. Peng, B. Wang, S. Yao, and Z. Liu, "Review on cyber-physical systems," *IEEE/CAA J. Automat. Sinica*, vol. 4, no. 1, pp. 27–40, Jan. 2017.

[46] J. Lee, M. Azamfar, and J. Singh, "A blockchain enabled cyber-physical system architecture for industry 4.0 manufacturing systems," *Manuf. Lett.*, vol. 20, pp. 34–39, Apr. 2019.

[47] C. Ruzsa, "Digital twin technology–external data resources in creating the model and classification of different digital twin types in manufacturing," *Proc. Manuf.*, vol. 54, pp. 209–215, Jan. 2021.
[48] W. Tushar, N. Wijerathne, W.-T. Li, C. Yuen, H. V. Poor, T. K. Saha, and K. L. Wood, "Internet of Things for green building management: Disruptive innovations through low-cost sensor technology and artificial intelligence," *IEEE Signal Process. Mag.*, vol. 35, no. 5, pp. 100–110, Sep. 2018.
[49] A. Burg, A. Chattopadhyay, and K. Y. Lam, "Wireless communication and security issues for cyber-physical systems and the Internet-of-Things," *Proc. IEEE*, vol. 106, no. 1, pp. 38–60, Jan. 2018.
[50] S. Li, Q. Ni, Y. Sun, G. Min, and S. Al-Rubaye, "Energy-efficient resource allocation for industrial cyber-physical IoT systems in 5G era," *IEEE Trans. Ind. Informat.*, vol. 14, no. 6, pp. 2618–2628, Jun. 2018.
[51] M. Krugh and L. Mears, "A complementary cyber-human systems framework for industry 4.0 cyber-physical systems," *Manuf. Lett.*, vol. 15, pp. 89–92, Jan. 2018.
[52] E. Yaacoub, K. Abualsaud, T. Khattab, M. Guizani, and A. Chehab, "Secure mHealth IoT data transfer from the patient to the hospital: A three-tier approach," *IEEE Wireless Commun.*, vol. 26, no. 5, pp. 70–76, Oct. 2019.
[53] D. Yin, X. Ming, and X. Zhang, "Understanding data-driven cyber-physical-social system (D-CPSS) using a 7C framework in social manufacturing context," *Sensors*, vol. 20, no. 18, p. 5319, Sep. 2020.
[54] U. Adhikari, T. Morris, and S. Pan, "WAMS cyber-physical test bed for power system, cybersecurity study, and data mining," *IEEE Trans. Smart Grid*, vol. 8, no. 6, pp. 2744–2753, Nov. 2017.
[55] W. Gan, J. C. Lin, H. Chao, and J. Zhan, "Data mining in distributed environment: A survey," *WIREs Data Mining Knowl. Discovery*, vol. 7, no. 6, p. 1216, Jul. 2017.
[56] S. Zhan, Z. Liu, A. Chong, and D. Yan, "Building categorization revisited: A clustering-based approach to using smart meter data for building energy benchmarking," *Appl. Energy*, vol. 269, Jul. 2020, Art. no. 114920.
[57] X. Gui, Z. Gou, and F. Zhang, "The relationship between energy use and space use of higher educational buildings in subtropical Australia," *Energy Buildings*, vol. 211, Mar. 2020, Art. no. 109799.
[58] R. Zhang, A. Ishikawa, W. Wang, B. Striner, and O. K. Tonguz, "Using reinforcement learning with partial vehicle detection for intelligent traffic signal control," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 1, pp. 404–415, Jan. 2021.
[59] S. Hussein, P. Kandel, C. W. Bolan, M. B. Wallace, and U. Bagci, "Lung and pancreatic tumor characterization in the deep learning era: Novel supervised and unsupervised learning approaches," *IEEE Trans. Med. Imag.*, vol. 38, no. 8, pp. 1777–1787, Aug. 2019.
[60] Y. Yang, W. Li, T. A. Gulliver, and S. Li, "Bayesian deep learning-based probabilistic load forecasting in smart grids," *IEEE Trans. Ind. Informat.*, vol. 16, no. 7, pp. 4703–4713, Jul. 2020.
[61] M. Chen, W. Saad, and C. Yin, "Liquid state machine learning for resource and cache management in LTE-U unmanned aerial vehicle (UAV) networks," *IEEE Trans. Wireless Commun.*, vol. 18, no. 3, pp. 1504–1517, Mar. 2019.
[62] F. Tao, H. Zhang, A. Liu, and A. Y. C. Nee, "Digital twin in industry: State-of-the-art," *IEEE Trans. Ind. Informat.*, vol. 15, no. 4, pp. 2405–2415, Apr. 2019.
[63] M. M. Armstrong. (Dec. 2020). *Cheat sheet: What is Digital Twin?*. Accessed: Aug. 17, 2021. [Online]. Available: https://www.ibm.com/blogs/internet-of-things/iot-cheat-sheet-digital-twin/
[64] S. Ma, Y. Zhang, J. Lv, H. Yang, and J. Wu, "Energy-cyber-physical system enabled management for energy-intensive manufacturing industries," *J. Clean. Prod.*, vol. 226, pp. 892–903, Jul. 2019.
[65] A. A. Khan, M. M. Khan, K. M. Khan, J. Arshad, and F. Ahmad, "A blockchain-based decentralized machine learning framework for collaborative intrusion detection within UAVs," *Comput. Netw.*, vol. 196, Sep. 2021, Art. no. 108217.
[66] N. Hajiheydari, M. S. Delgosha, and H. Olya, "Scepticism and resistance to IoMT in healthcare: Application of behavioural reasoning theory with configurational perspective," *Technol. Forecasting Social Change*, vol. 169, Aug. 2021, Art. no. 120807.
[67] C.-W. Ten, G. Manimaran, and C.-C. Liu, "Cybersecurity for critical infrastructures: Attack and defense modeling," *IEEE Trans. Syst., Man, Cybern. A, Syst. Humans*, vol. 40, no. 4, pp. 853–865, Jul. 2010.
[68] S. Sridhar, A. Hahn, and M. Govindarasu, "Cyber-physical system security for the electric power grid," *Proc. IEEE*, vol. 100, no. 1, pp. 210–224, Jan. 2012.
[69] A. Humayed, J. Lin, F. Li, and B. Luo, "Cyber-physical systems security—A survey," *IEEE Internet Things J.*, vol. 4, no. 6, pp. 1802–1831, Dec. 2017.
[70] L. P. Rondon, L. Babun, A. Aris, K. Akkaya, and A. S. Uluagac, "PoisonIvy: (In)secure practices of enterprise IoT systems in smart buildings," in *Proc. 7th ACM Int. Conf. Syst. Energy-Efficient Buildings, Cities, Transp.*, New York, NY, USA, Nov. 2020, pp. 130–139.
[71] C. Peng, H. Sun, M. Yang, and Y.-L. Wang, "A survey on security communication and control for smart grids under malicious cyber attacks," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 49, no. 8, pp. 1554–1569, Aug. 2019.
[72] H. Zhang, B. Liu, and H. Wu, "Smart grid cyber-physical attack and defense: A review," *IEEE Access*, vol. 9, pp. 29641–29659, 2021.
[73] P. Kumar, Y. Lin, G. Bai, A. Paverd, J. S. Dong, and A. Martin, "Smart grid metering networks: A survey on security, privacy and open research issues," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 3, pp. 2886–2927, Feb. 2019.
[74] A. S. Musleh, G. Chen, and Z. Y. Dong, "A survey on the detection algorithms for false data injection attacks in smart grids," *IEEE Trans. Smart Grid*, vol. 11, no. 3, pp. 2218–2234, May 2020.
[75] M. N. Kurt, O. Ogundijo, C. Li, and X. Wang, "Online cyber-attack detection in smart grid: A reinforcement learning approach," *IEEE Trans. Smart Grid*, vol. 10, no. 5, pp. 5174–5185, Sep. 2019.
[76] Y. Li, L. Zhang, Z. Lv, and W. Wang, "Detecting anomalies in intelligent vehicle charging and station power supply systems with multi-head attention models," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 1, pp. 555–564, Jan. 2021.
[77] P. Bagga, A. K. Das, M. Wazid, J. J. Rodrigues, K.-K. R. Choo, and Y. Park, "On the design of mutual authentication and key agreement protocol in internet of vehicles-enabled intelligent transportation system," *IEEE Trans. Veh. Technol.*, vol. 70, no. 2, pp. 1736–1751, Jan. 2021.
[78] F. Qiao, J. Wu, J. Li, A. Bashir, S. Mumtaz, and U. Tariq, "Trustworthy edge storage orchestration in intelligent transportation systems using reinforcement learning," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 7, pp. 4443–4456, Jul. 2021.
[79] O. Kocabas, T. Soyata, and M. K. Aktas, "Emerging security mechanisms for medical cyber physical systems," *IEEE/ACM Trans. Comput. Biol. Bioinf.*, vol. 13, no. 3, pp. 401–416, May/Jun. 2016.
[80] A. Rao, N. Carreon, R. Lysecky, and J. Rozenblit, "Probabilistic threat detection for risk management in cyber-physical medical systems," *IEEE Softw.*, vol. 35, no. 1, pp. 38–43, Jan. 2018.
[81] A. Razaque, F. Amsaad, M. J. Khan, S. Hariri, S. Chen, C. Siting, and X. Ji, "Survey: Cybersecurity vulnerabilities, attacks and solutions in the medical domain," *IEEE Access*, vol. 7, pp. 168774–168797, 2019.
[82] Y. Xu, T. Zhang, D. Yang, Y. Liu, and M. Tao, "Joint resource and trajectory optimization for security in UAV-assisted MEC systems," *IEEE Trans. Commun.*, vol. 69, no. 1, pp. 573–588, Jan. 2021.
[83] M. Kim, S. Kim, and J. Lee, "Securing communications with friendly unmanned aerial vehicle jammers," *IEEE Trans. Veh. Technol.*, vol. 70, no. 2, pp. 1972–1977, Feb. 2021.
[84] A. Shafique, A. Mehmood, and M. Elhadef, "Survey of security protocols and vulnerabilities in unmanned aerial vehicles," *IEEE Access*, vol. 9, pp. 46927–46948, 2021.
[85] N. Mohamed, J. Al-Jaroodi, I. Jawhar, and N. Kesserwan, "Data-driven security for smart city systems: Carving a trail," *IEEE Access*, vol. 8, pp. 147211–147230, 2020.
[86] M. Sookhak, H. Tang, Y. He, and F. R. Yu, "Security and privacy of smart cities: A survey, research issues and challenges," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 2, pp. 1718–1743, Aug. 2019.
[87] A. Akhunzada, S. U. Islam, and S. Zeadally, "Securing cyberspace of future smart cities with 5G technologies," *IEEE Netw.*, vol. 34, no. 4, pp. 336–342, Jul. 2020.
[88] M. A. Ferrag, L. Shu, X. Yang, A. Derhab, and L. Maglaras, "Security and privacy for green IoT-based agriculture: Review, blockchain solutions, and challenges," *IEEE Access*, vol. 8, pp. 32031–32053, 2020.
[89] H.-T. Wu and C.-W. Tsai, "An intelligent agriculture network security system based on private blockchains," *J. Commun. Netw.*, vol. 21, no. 5, pp. 503–508, Oct. 2019.

[90] A. Vangala, A. K. Das, N. Kumar, and M. Alazab, "Smart secure sensing for IoT-based agriculture: Blockchain perspective," *IEEE Sensors J.*, vol. 21, no. 16, pp. 17591–17607, Aug. 2021.

[91] A. John, S. Mohan, and D. M. M. Vianny, "Cognitive cyber-physical system applications," in *Cognitive Engineering for Next Generation Computing: A Practical Analytical Approach*, K. B. Prakash, G. R. Kanagachidambaresan, and E. V. V. Srikanth, Eds. Beverly, MA, USA: Scrivener Publishing, Apr. 2021, pp. 167–187, ch. 6.

[92] S. Han, K.-Y. Lam, D. Chen, M. Xiong, J. Wang, K. Ramamritham, and A. K. Mok, "Online mode switch algorithms for maintaining data freshness in dynamic cyber-physical systems," *IEEE Trans. Knowl. Data Eng.*, vol. 28, no. 3, pp. 756–769, Mar. 2016.

[93] A. Afrizal, B. Mulyanti, and I. Widiaty, "Development of cyber-physical system (CPS) implementation in industry 4.0," in *Proc. IOP Conf. Series: Mater. Sci. Eng.*, vol. 830, no. 4, Apr. 2020, Art. no. 042090.

[94] J. Reinders, B. Hunnekens, F. Heck, T. Oomen, and N. van de Wouw, "Adaptive control for mechanical ventilation for improved pressure support," *IEEE Trans. Control Syst. Technol.*, vol. 29, no. 1, pp. 180–193, Jan. 2021.

[95] O. Kisi, P. Khosravinia, S. Heddam, B. Karimi, and N. Karimi, "Modeling wetting front redistribution of drip irrigation systems using a new machine learning method: Adaptive neuro-fuzzy system improved by hybrid particle swarm optimization–gravity search algorithm," *Agricult. Water Manage.*, vol. 256, Oct. 2021, Art. no. 107067.

[96] J. J. Roldan, E. Pena-Tapia, P. Garcia-Aunon, J. Del Cerro, and A. Barrientos, "Bringing adaptive and immersive interfaces to real-world multi-robot scenarios: Application to surveillance and intervention in infrastructures," *IEEE Access*, vol. 7, pp. 86319–86335, 2019.

[97] M. Esrafilian-Najafabadi and F. Haghighat, "Occupancy-based HVAC control systems in buildings: A state-of-the-art review," *Building Environ.*, vol. 197, Jun. 2021, Art. no. 107810.

[98] A.-H. Mohsenian-Rad, V. W. S. Wong, J. Jatskevich, R. Schober, and A. Leon-Garcia, "Autonomous demand-side management based on game-theoretic energy consumption scheduling for the future smart grid," *IEEE Trans. Smart Grid*, vol. 1, no. 3, pp. 320–331, Dec. 2010.

[99] L. Hao, B. Sun, G. Li, and L. Guo, "The eco-driving considering coordinated control strategy for the intelligent electric vehicles," *IEEE Access*, vol. 9, pp. 10686–10698, 2021.

[100] A. Papacharalampopoulos, P. Stavropoulos, and J. Stavridis, "Adaptive control of thermal processes: Laser welding and additive manufacturing paradigms," *Proc. CIRP*, vol. 67, pp. 233–237, Jan. 2018.

[101] S. Tan, D. De, W.-Z. Song, J. Yang, and S. K. Das, "Survey of security advances in smart grid: A data driven approach," *IEEE Commun. Surveys Tuts.*, vol. 19, no. 1, pp. 397–422, 1st Quart., 2017.

[102] W.-T. Li, S. R. Gubba, W. Tushar, C. Yuen, N. U. Hassan, H. V. Poor, K. L. Wood, and C.-K. Wen, "Data driven electricity management for residential air conditioning systems: An experimental approach," *IEEE Trans. Emerg. Topics Comput.*, vol. 7, no. 3, pp. 380–391, Jul. 2019.

[103] H. Bolhasani, M. Mohseni, and A. M. Rahmani, "Deep learning applications for IoT in health care: A systematic review," *Informat. Med. Unlocked*, vol. 23, Jan. 2021, Art. no. 100550.

[104] M. Mohammadi, A. Al-Fuqaha, M. Guizani, and J. Oh, "Semisupervised deep reinforcement learning in support of IoT and smart city services," *IEEE Internet Things J.*, vol. 5, no. 2, pp. 624–635, Apr. 2018.

[105] H. Zhang, M. Babar, M. U. Tariq, M. A. Jan, V. G. Menon, and X. Li, "SafeCity: Toward safe and secured data management design for IoT-enabled smart city planning," *IEEE Access*, vol. 8, pp. 145256–145267, 2020.

[106] X. Zhang, J. Wang, H. Zhang, L. Li, M. Pan, and Z. Han, "Data-driven transportation network company vehicle scheduling with Users' location differential privacy preservation," *IEEE Trans. Mobile Comput.*, vol. 22, no. 2, pp. 813–823, Feb. 2023, doi: 10.1109/TMC.2021.3091148.

[107] M. P. Polverini, S. Formentin, L. Merzagora, and P. Rocco, "Mixed data-driven and model-based robot implicit force control: A hierarchical approach," *IEEE Trans. Control Syst. Technol.*, vol. 28, no. 4, pp. 1258–1271, Jul. 2020.

[108] K. L.-M. Ang and J. K. P. Seng, "Big data and machine learning with hyperspectral information in agriculture," *IEEE Access*, vol. 9, pp. 36699–36718, 2021.

[109] D. Wang, "Building value in a world of technological change: Data analytics and industry 4.0," *IEEE Eng. Manag. Rev.*, vol. 46, no. 1, pp. 32–33, Mar. 2018.

[110] L. D. Xu and L. Duan, "Big data for cyber physical systems in industry 4.0: A survey," *Enterprise Inf. Syst.*, vol. 13, no. 2, pp. 148–169, Feb. 2019.

[111] G. D'Emilia, A. Gaspari, and E. Natale, "Accuracy improvement of measurement management systems: Requirements for reliability of data and practical examples," in *Proc. IEEE Int. Instrum. Meas. Technol. Conf. (IMTC)*, Dubrovnik, Croatia, May 2020, pp. 1–6.

[112] H. Guo, J. Liu, and L. Zhao, "Big data acquisition under failures in FiWi enhanced smart grid," *IEEE Trans. Emerg. Topics Comput.*, vol. 7, no. 3, pp. 420–432, Jul. 2019.

[113] S. Yu, M. Chen, E. Zhang, J. Wu, H. Yu, Z. Yang, L. Ma, X. Gu, and W. Lu, "Robustness study of noisy annotation in deep learning based medical image segmentation," *Phys. Med. Biol.*, vol. 65, no. 17, Aug. 2020, Art. no. 175007.

[114] Y. Bouabdallaoui, Z. Lafhaj, P. Yim, L. Ducoulombier, and B. Bennadji, "Predictive maintenance in building facilities: A machine learning-based approach," *Sensors*, vol. 21, no. 4, p. 1044, Feb. 2021.

[115] M. W. Hoffmann, S. Wildermuth, R. Gitzel, A. Boyaci, J. Gebhardt, H. Kaul, I. Amihai, B. Forg, M. Suriyah, T. Leibfried, V. Stich, J. Hicking, M. Bremer, L. Kaminski, D. Beverungen, P. Z. Heiden, and T. Tornede, "Integration of novel sensors and machine learning for predictive maintenance in medium voltage switchgear to enable the energy and mobility revolutions," *Sensors*, vol. 20, no. 7, p. 2099, Apr. 2020.

[116] G. Karaduman and E. Akin, "A new approach based on predictive maintenance using the fuzzy classifier in pantograph-catenary systems," *IEEE Trans.Intell. Transp. Syst.*, vol. 23, no. 5, pp. 1–11, May 2020, doi: 10.1109/TITS.2020.3042997.

[117] A. V. Malawade, N. D. Costa, D. Muthirayan, P. P. Khargonekar, and M. A. Al Faruque, "Neuroscience-inspired algorithms for the predictive maintenance of manufacturing systems," *IEEE Trans. Ind. Informat.*, vol. 17, no. 12, pp. 7980–7990, Dec. 2021.

[118] A. Shamayleh, M. Awad, and J. Farhat, "IoT based predictive maintenance management of medical equipment," *J. Med. Syst.*, vol. 44, no. 4, p. 72, Feb. 2020.

[119] Y. Tang, S. Dananjayan, C. Hou, Q. Guo, S. Luo, and Y. He, "A survey on the 5G network and its impact on agriculture: Challenges and opportunities," *Comput. Electron. Agricult.*, vol. 180, Jan. 2021, Art. no. 105895.

[120] P. Aivaliotis, Z. Arkouli, K. Georgoulias, and S. Makris, "Degradation curves integration in physics-based models: Towards the predictive maintenance of industrial robots," *Robot. Comput.-Integr. Manuf.*, vol. 71, Oct. 2021, Art. no. 102177.

[121] W. Tushar, C. Yuen, T. K. Saha, T. Morstyn, A. C. Chapman, M. J. E. Alam, S. Hanif, and H. V. Poor, "Peer-to-peer energy systems for connected communities: A review of recent advances and emerging challenges," *Appl. Energy*, vol. 282, Jan. 2021, Art. no. 116131.

[122] C. P. Mediwaththe and D. B. Smith, "Game-theoretic electric vehicle charging management resilient to non-ideal user behavior," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 11, pp. 3486–3495, Nov. 2018.

[123] M. Yu and S. H. Hong, "Supply–demand balancing for power management in smart grid: A Stackelberg game approach," *Appl. Energy*, vol. 164, pp. 702–710, Feb. 2016.

[124] C. P. Mediwaththe and L. Blackhall, "Network-aware demand-side management framework with a community energy storage system considering voltage constraints," *IEEE Trans. Power Syst.*, vol. 36, no. 2, pp. 1229–1238, Mar. 2021.

[125] Z. Ning, P. Dong, X. Wang, X. Hu, L. Guo, B. Hu, Y. Guo, T. Qiu, and R. Y. K. Kwok, "Mobile edge computing enabled 5g health monitoring for internet of medical things: A decentralized game theoretic approach," *IEEE J. Sel. Areas Commun.*, vol. 39, no. 2, pp. 463–478, Feb. 2021.

[126] Q. Cui, X. Wang, X. Wang, and Y. Zhang, "Residential appliances direct load control in real-time using cooperative game," *IEEE Trans. Power Syst.*, vol. 31, no. 1, pp. 226–233, Jan. 2016.

[127] N. Han, J. Luo, and L. Zong, "Cooperative game method for on-orbit substructure transportation using modular robots," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 58, no. 2, pp. 1161–1175, Apr. 2021, doi: 10.1109/TAES.2021.3111141.

[128] P. Chakraborty, E. Baeyens, K. Poolla, P. P. Khargonekar, and P. Varaiya, "Sharing storage in a smart grid: A coalitional game approach," *IEEE Trans. Smart Grid*, vol. 10, no. 4, pp. 4379–4390, Jul. 2019.

[129] M. Guajardo and M. Rönnqvist, "A review on cost allocation methods in collaborative transportation," *Int. Trans. Oper. Res.*, vol. 23, no. 3, pp. 371–392, May 2016.

[130] C. Han, D. Chang, and F. Meng, "Research on conflict resolution method of production evaluation index in flexible manufacturing field based on multiplayer cooperative game," *IEEE Access*, vol. 9, pp. 7336–7352, 2021.

[131] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Comput. Netw.*, vol. 54, no. 15, pp. 2787–2805, Jun. 2010.

[132] M. Raj, S. Gupta, V. Chamola, A. Elhence, T. Garg, M. Atiquzzaman, and D. Niyato, "A survey on the role of Internet of Things for adopting and promoting agriculture 4.0," *J. Netw. Comput. Appl.*, vol. 187, Aug. 2021, Art. no. 103107.

[133] C.-H. Yang, K.-C. Lee, and S.-E. Li, "A mixed activity-based costing and resource constraint optimal decision model for IoT-oriented intelligent building management system portfolios," *Sustain. Cities Soc.*, vol. 60, Sep. 2020, Art. no. 102142.

[134] C. Lyu, Y. Jia, and Z. Xu, "Fully decentralized peer-to-peer energy sharing framework for smart buildings with local battery system and aggregated electric vehicles," *Appl. Energy*, vol. 299, Oct. 2021, Art. no. 117243.

[135] T. K. L. Hui, R. S. Sherratt, and D. D. Sanchez, "Major requirements for building smart Homes in smart cities based on Internet of Things technologies," *Future Generat. Comput. Syst.*, vol. 76, pp. 358–369, Nov. 2017.

[136] W. Liang, Z. Ning, S. Xie, Y. Hu, S. Lu, and D. Zhang, "Secure fusion approach for the Internet of Things in smart autonomous multi-robot systems," *Inf. Sci.*, vol. 579, pp. 468–482, Jun. 2021.

[137] E. Colle and S. Galerne, "A multihypothesis set approach for mobile robot localization using heterogeneous measurements provided by the Internet of Things," *Robot. Auto. Syst.*, vol. 96, pp. 102–113, Oct. 2017.

[138] D. G. S. Pivoto, L. F. F. de Almeida, R. da Rosa Righi, J. J. P. C. Rodrigues, A. B. Lugli, and A. M. Alberti, "Cyber-physical systems architectures for industrial Internet of Things applications in industry 4.0: A literature review," *J. Manuf. Syst.*, vol. 58, pp. 176–192, Jan. 2021.

[139] S. Ketu and P. K. Mishra, "Internet of Healthcare Things: A contemporary survey Author links open overlay panel," *J. Netw. Comput. Appl.*, vol. 192, Oct. 2021, Art. no. 103179.

[140] J. Leng, D. Wang, W. Shen, X. Li, Q. Liu, and X. Chen, "Digital twins-based smart manufacturing system design in industry 4.0: A review," *J. Manuf. Syst.*, vol. 60, pp. 119–137, Jul. 2021.

[141] N. D. Brunetti, G. Dellegrottaglie, G. Di Giuseppe, and M. Di Biase, "Remote tele-medicine cardiologist support for care manager nursing of chronic cardiovascular disease: Preliminary report," *Int. J. Cardiology*, vol. 176, no. 2, pp. 552–556, Sep. 2014.

[142] S. Radhakrishnan, S. G. Nair, and J. Isaac, "Multilayer perceptron neural network model development for mechanical ventilator parameters prediction by real time system learning," *Biomed. Signal Process. Control*, vol. 71, Jan. 2022, Art. no. 103170.

[143] V. Marinakis, C. Karakosta, H. Doukas, S. Androulaki, and J. Psarras, "A building automation and control tool for remote and real time monitoring of energy consumption," *Sustain. Cities Soc.*, vol. 6, pp. 11–15, Feb. 2013.

[144] K. P. Guddanti, A. R. R. Matavalam, and Y. Weng, "PMU-based distributed non-iterative algorithm for real-time voltage stability monitoring," *IEEE Trans. Smart Grid*, vol. 11, no. 6, pp. 5203–5215, Nov. 2020.

[145] Q. Chen, F. Wang, B.-M. Hodge, J. Zhang, Z. Li, M. Shafie-Khah, and J. P. S. Catalao, "Dynamic price vector formation model-based automatic demand response strategy for pv-assisted ev charging stations," *IEEE Trans. Smart Grid*, vol. 8, no. 6, pp. 2903–2915, Nov. 2017.

[146] A. Goap, D. Sharma, A. K. Shukla, and C. R. Krishna, "An IoT based smart irrigation management system using Machine learning and open source technologies," *Comput. Electron. Agricult.*, vol. 155, pp. 41–49, Dec. 2018.

[147] P. O. Dusadeerungsikul and S. Y. Nof, "A collaborative control protocol for agricultural robot routing with online adaptation," *Comput. Ind. Eng.*, vol. 135, pp. 456–466, Sep. 2019.

[148] A. Bigdelou, L. Schwarz, and N. Navab, "An adaptive solution for intra-operative gesture-based human-machine interaction," in *Proc. ACM Int. Conf. Intell. User Interfaces*, Lisbon, Portugal, Feb. 2012, pp. 75–84.

[149] A. Noula and D. Ioannidis. (Dec. 2018). *eDREAM: Requirement-Driven System Development V1*. Accessed: Sep. 23, 2021. [Online]. Available: https://edream-h2020.eu/wp-content/uploads/2019/02/eDREAM.D2.4.CERTH_.WP2_.V1.0-compressed.pdf

[150] C. Clabaugh and M. Matarić, "Robots for the people, by the people: Personalizing human-machine interaction," *Sci. Robot.*, vol. 3, no. 21, pp. 1–2, Aug. 2018.

[151] V. Papakostopoulos, D. Nathanael, E. Portouli, and A. Amditis, "Effect of external HMI for automated vehicles (AVs) on drivers' ability to infer the AV motion intention: A field experiment," *Transp. Res. F, Traffic Psychol. Behaviour*, vol. 82, pp. 32–42, Oct. 2021.

[152] J. Wilhelm, C. Petzoldt, T. Beinke, and M. Freitag, "Review of digital twin-based interaction in smart manufacturing: Enabling cyber-physical systems for human-machine interaction," *Int. J. Comput. Integr. Manuf.*, vol. 34, pp. 1–18, Sep. 2021, doi: 10.1080/0951192X.2021.1963482.

[153] R. Marcelino, L. C. Casagrande, R. Cunha, Y. Crotti, and V. Gruber, "Internet of Things applied to precision agriculture," *Online Eng. Internet Things*, vol. 22, pp. 499–509, Sep. 2017.

[154] S. Morgan. (Nov. 2020). *Cybercrime to Cost the World $10.5 Trillion Annually by 2025*. Accessed: Sep. 23, 2021. [Online]. Available: https://cybersecurityventures.com/hackerpocalypse-cybercrime-report-2016/

[155] M. Mylrea and S. N. G. Gourisetti, "Cybersecurity and optimization in smart 'autonomous' buildings," in *Autonomy and Artificial Intelligence: A Threat or Savior?*, W. F. Lawless, R. Mittu, D. Sofge, and S. Russell, Eds. New York, NY, USA: Springer, Aug. 2017, pp. 263–294, ch. 1.

[156] A. Chehri, I. Fofana, and X. Yang, "Security risk modeling in smart grid critical infrastructures in the era of big data and artificial intelligence," *Sustainability*, vol. 13, no. 6, p. 3196, Mar. 2021.

[157] T. Mecheva and N. Kakanakov, "Cybersecurity in intelligent transportation systems," *MDPI Comput.*, vol. 9, no. 4, p. 83, Oct. 2020.

[158] R. O. Andrade, S. G. Yoo, L. Tello-Oquendo, and I. Ortiz-Garces, "A comprehensive study of the IoT cybersecurity in smart cities," *IEEE Access*, vol. 8, pp. 228922–228941, 2020.

[159] J. Wu, K. Ota, M. Dong, J. Li, and H. Wang, "Big data analysis-based security situational awareness for smart grid," *IEEE Trans. Big Data*, vol. 4, no. 3, pp. 408–417, Sep. 2018.

[160] J. Qian, Z. Cao, M. Lu, X. Chen, J. Shen, and J. Liu, "The secure lattice-based data aggregation scheme in residential networks for smart grid," *IEEE Internet Things J.*, vol. 9, no. 3, pp. 1–12, Feb. 2021, early access, doi: 10.1109/JIOT.2021.3090270.

[161] J. Wang, L. Wu, H. Wang, K.-K.-R. Choo, and D. He, "An efficient and privacy-preserving outsourced support vector machine training for Internet of Medical Things," *IEEE Internet Things J.*, vol. 8, no. 1, pp. 458–473, Jan. 2021.

[162] A. Rahman, M. S. Hossain, N. A. Alrajeh, and F. Alsolami, "Adversarial examples—Security threats to COVID-19 deep learning systems in medical IoT devices," *IEEE Internet Things J.*, vol. 8, no. 12, pp. 9603–9610, Jun. 2021.

[163] X. Xu, H. Zhao, H. Yao, and S. Wang, "A blockchain-enabled energy-efficient data collection system for UAV-assisted IoT," *IEEE Internet Things J.*, vol. 8, no. 4, pp. 2431–2443, Feb. 2021.

[164] M. U. Hassan, M. H. Rehmani, and J. Chen, "Differential privacy techniques for cyber physical systems: A survey," *IEEE Commun. Surveys Tuts.*, vol. 22, no. 1, pp. 746–789, 1st Quart., 2019.

[165] A. H. Buckman, M. Mayfield, and S. B. M. Beck, "What is a smart building?" *Smart Sustain. Built Environ.*, vol. 3, no. 2, pp. 92–109, Sep. 2014.

[166] P. Li, Y. Lu, D. Yan, J. Xiao, and H. Wu, "Scientometric mapping of smart building research: Towards a framework of human-cyber-physical system (HCPS)," *Autom. Construction*, vol. 129, Sep. 2021, Art. no. 103776.

[167] A. H. Oti, E. Kurul, F. Cheung, and J. H. M. Tah, "A framework for the utilization of building management system data in building information models for building design and operation," *Autom. Construct.*, vol. 72, pp. 195–210, Dec. 2016.

[168] J. Song, Y. Lee, and E. Hwang, "Time–frequency mask estimation based on deep neural network for flexible load disaggregation in buildings," *IEEE Trans. Smart Grid*, vol. 12, no. 4, pp. 3242–3251, Jul. 2021.

[169] A. P. Plageras, K. E. Psannis, C. Stergiou, H. Wang, and B. B. Gupta, "Efficient IoT-based sensor BIG data collection–processing and analysis in smart buildings," *Future Gener. Comput. Syst.*, vol. 82, pp. 349–357, May 2018.

[170] M. U. Mehmood, D. Chun, Zeeshan, H. Han, G. Jeon, and K. Chen, "A review of the applications of artificial intelligence and big data to buildings for energy-efficiency and a comfortable indoor living environment," *Energy Buildings*, vol. 202, Nov. 2019, Art. no. 109383.

[171] M. S. H. Nizami, M. J. Hossain, and E. Fernandez, "Multiagent-based transactive energy management systems for residential buildings with distributed energy resources," *IEEE Trans. Ind. Informat.*, vol. 16, no. 3, pp. 1836–1847, Mar. 2020.

[172] A. Gopstein, C. Nguyen, C. O'Fallon, and D. Wollman, "NIST framework and roadmap for smart grid interoperability standards, release 4.0," Nat. Inst. Standards Technol., U.S. Dept. Commerce, Gaithersburg, MD, USA, Tech. Rep. 1108rev4, Feb. 2021, doi: 10.6028/NIST.SP.1108r4.

[173] M. Liserre, T. Sauter, and J. Y. Hung, "Future energy systems: Integrating renewable energy sources into the smart power grid through industrial electronics," *IEEE Ind. Electron. Mag.*, vol. 4, no. 1, pp. 18–37, Mar. 2010.

[174] National Institute of Standards and Technology. (Jan. 2010). *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0*. Accessed: Aug. 5, 2021. [Online]. Available: https://www.nist.gov/system/files/documents/public_affairs/releases/smartgrid_interoperability_final.pdf

[175] X. Fang, S. Misra, G. Xue, and D. Yang, "Smart grid—The new and improved power grid: A survey," *IEEE Commun. Surveys Tuts.*, vol. 14, no. 4, pp. 944–980, 4th Quart., 2012.

[176] D. Ranamuka, K. M. Muttaqi, and D. Sutanto, "Flexible AC power flow control in distribution systems by coordinated control of distributed solar-PV and battery energy storage units," *IEEE Trans. Sustain. Energy*, vol. 11, no. 4, pp. 2054–2062, Oct. 2020.

[177] A. Ghosal and M. Conti, "Key management systems for smart grid advanced metering infrastructure: A survey," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 3, pp. 2831–2848, Mar. 2019.

[178] M. Pilz and L. Al-Fagih, "Recent advances in local energy trading in the smart grid based on game-theoretic approaches," *IEEE Trans. Smart Grid*, vol. 10, no. 2, pp. 1363–1371, Mar. 2019.

[179] A. K. M. Baki, "Continuous monitoring of smart grid devices through multi protocol label switching," *IEEE Trans. Smart Grid*, vol. 5, no. 3, pp. 1210–1215, May 2014.

[180] A. Vallejo, A. Zaballos, J. M. Selga, and J. Dalmau, "Next-generation QoS control architectures for distribution smart grid communication networks," *IEEE Commun. Mag.*, vol. 50, no. 5, pp. 128–134, May 2012.

[181] F. Ege Abrahamsen, Y. Ai, and M. Cheffena, "Communication technologies for smart grid: A comprehensive survey," 2021, *arXiv:2103.11657*.

[182] Y. Feng, B. Hu, H. Hao, Y. Gao, Z. Li, and J. Tan, "Design of distributed cyber–physical systems for connected and automated vehicles with implementing methodologies," *IEEE Trans. Ind. Informat.*, vol. 14, no. 9, pp. 4200–4211, Sep. 2018.

[183] D. B. Rawat, C. Bajracharya, and G. Yan, "Towards intelligent transportation cyber-physical systems: Real-time computing and communications perspectives," in *Proc. SoutheastCon*, Fort Lauderdale, FL, USA, Apr. 2015, pp. 1–6.

[184] F. Zhu, Y. Lv, Y. Chen, X. Wang, and F. Wang, "Parallel transportation systems: Toward IoT-enabled smart urban traffic control and management," *IEEE Trans. Intell. Transp. Syst.*, vol. 21, no. 10, pp. 4063–4071, Oct. 2020.

[185] M. B. Mollah, J. Zhao, D. Niyato, Y. L. Guan, and L. H. Koh, "Blockchain for the Internet of Vehicles towards intelligent transportation systems: A survey," *IEEE Internet Things J.*, vol. 8, no. 6, pp. 4157–4185, Mar. 2021.

[186] M. H. K. Tushar, A. W. Zeineddine, and C. Assi, "Demand-side management by regulating charging and discharging of the EV, ESS, and utilizing renewable energy," *IEEE Trans. Ind. Informat.*, vol. 14, no. 1, pp. 117–126, Jan. 2018.

[187] H. Mehrjerdi and E. Rakhshani, "Vehicle-to-grid technology for cost reduction and uncertainty management integrated with solar power," *J. Cleaner Prod.*, vol. 229, pp. 463–469, Aug. 2019.

[188] M. Massar, I. Reza, S. M. Rahman, S. M. H. Abdullah, A. Jamal, and F. S. Al-Ismail, "Impacts of autonomous vehicles on greenhouse gas emissions - Positive or negative?" *Int. J. Environ. Res. Public Health*, vol. 18, no. 5567, pp. 1–23, May 2021.

[189] K. J. Parnell, N. A. Stanton, and K. L. Plant, "What's the law got to do with it? Legislation regarding in-vehicle technology use and its impact on driver distraction," *Accident Anal. Prevention*, vol. 100, pp. 1–14, Mar. 2017.

[190] J. Guerrero-Ibáñez, S. Zeadally, and J. Contreras-Castillo, "Sensor technologies for intelligent transportation systems," *Sensors*, vol. 18, no. 4, p. 1212, Apr. 2018.

[191] G. S. Tewolde, "Sensor and network technology for intelligent transportation systems," in *Proc. IEEE Int. Conf. Electro/Inf. Technol.*, Indianapolis, IN, USA, May 2012, pp. 1–7.

[192] A. J. V. Neto, Z. Zhao, J. J. P. C. Rodrigues, H. B. Camboim, and T. Braun, "Fog-based crime-assistance in smart IoT transportation system," *IEEE Access*, vol. 6, pp. 11101–11111, 2018.

[193] P. P. F. Balbin, J. C. R. Barker, C. K. Leung, M. Tran, R. P. Wall, and A. Cuzzocrea, "Predictive analytics on open big data for supporting smart transportation services," *Proc. Comput. Sci.*, vol. 176, pp. 3009–3018, Jan. 2020.

[194] L. S. Iyer, "AI enabled applications towards intelligent transportation," *Transp. Eng.*, vol. 5, Sep. 2021, Art. no. 100083.

[195] W. Guo, J. Li, X. Liu, and Y. Yang, "Privacy-preserving compressive sensing for real-time traffic monitoring in urban city," *IEEE Trans. Veh. Technol.*, vol. 69, no. 12, pp. 14510–14522, Dec. 2020.

[196] M. Sepulcre and J. Gozalvez, "Heterogeneous V2V communications in multi-link and multi-RAT vehicular networks," *IEEE Trans. Mobile Comput.*, vol. 20, no. 1, pp. 162–173, Jan. 2021.

[197] I. Lee, O. Sokolsky, S. Chen, J. Hatcliff, E. Jee, B. Kim, A. King, M. Mullen-Fortino, S. Park, A. Roederer, and K. K. Venkatasubramanian, "Challenges and research directions in medical cyber-physical systems," *Proc. IEEE*, vol. 100, no. 1, pp. 75–90, Jan. 2012.

[198] N. Dey, A. S. Ashour, F. Shi, S. J. Fong, and J. M. R. Tavares, "Medical cyber-physical systems: A survey," *J. Med. Syst.*, vol. 42, no. 4, p. 74, 2018.

[199] O. R. Shishvan, D.-S. Zois, and T. Soyata, "Machine intelligence in healthcare and medical cyber physical systems: A survey," *IEEE Access*, vol. 6, pp. 46419–46494, 2018.

[200] Z. Wang and A. M. Fey, "Deep learning with convolutional neural network for objective skill evaluation in robot-assisted surgery," *Int. J. Comput. Assist. Radiol. Surg.*, vol. 13, no. 12, pp. 1959–1970, Sep. 2018.

[201] P. Tokekar, J. V. Hook, D. Mulla, and V. Isler, "Sensor planning for a symbiotic UAV and UGV system for precision agriculture," *IEEE Trans. Robot.*, vol. 32, no. 6, pp. 1498–1511, Dec. 2016.

[202] D. Wang, P. Hu, J. Du, P. Zhou, T. Deng, and M. Hu, "Routing and scheduling for hybrid truck-drone collaborative parcel delivery with independent and truck-carried drones," *IEEE Internet Things J.*, vol. 6, no. 6, pp. 10483–10495, Dec. 2019.

[203] K. Asadi, A. K. Suresh, A. Ender, S. Gotad, S. Maniyar, S. Anand, M. Noghabaei, K. Han, E. Lobaton, and T. Wu, "An integrated UGV-UAV system for construction site data collection," *Autom. Construct.*, vol. 112, Apr. 2020, Art. no. 103068.

[204] A. Nourmohammadi, M. Jafari, and T. O. Zander, "A survey on unmanned aerial vehicle remote control using brain–computer interface," *IEEE Trans. Human-Mach. Syst.*, vol. 48, no. 4, pp. 337–348, Aug. 2018.

[205] H. Qin, Z. Meng, W. Meng, X. Chen, H. Sun, F. Lin, and M. H. Ang, "Autonomous exploration and mapping system using heterogeneous UAVs and UGVs in GPS-denied environments," *IEEE Trans. Veh. Technol.*, vol. 68, no. 2, pp. 1339–1350, Feb. 2019.

[206] S. V. Sibanyoni, D. T. Ramotsoela, B. J. Silva, and G. P. Hancke, "A 2-D acoustic source localization system for drones in search and rescue missions," *IEEE Sensors J.*, vol. 19, no. 1, pp. 332–341, Jan. 2019.

[207] Q. Yang and S.-J. Yoo, "Optimal UAV path planning: Sensing data acquisition over IoT sensor networks using multi-objective bio-inspired algorithms," *IEEE Access*, vol. 6, pp. 13671–13684, 2018.

[208] X. Liu, M. Chen, Y. Liu, Y. Chen, S. Cui, and L. Hanzo, "Artificial intelligence aided next-generation networks relying on UAVs," *IEEE Wireless Commun.*, vol. 28, no. 1, pp. 120–127, Feb. 2021.

[209] K. Wang, C. Pan, H. Ren, W. Xu, L. Zhang, and A. Nallanathan, "Packet error probability and effective throughput for ultra-reliable and low-latency UAV communications," *IEEE Trans. Commun.*, vol. 69, no. 1, pp. 73–84, Jan. 2021.

[210] K. Chen, Y. Wang, J. Zhao, X. Wang, and Z. Fei, "URLLC-oriented joint power control and resource allocation in UAV-assisted networks," *IEEE Internet Things J.*, vol. 8, no. 12, pp. 10103–10116, Jun. 2021.

[211] H. Wang, H. Zhao, J. Zhang, D. Ma, J. Li, and J. Wei, "Survey on unmanned aerial vehicle networks: A cyber physical system perspective," *IEEE Commun. Surveys Tuts.*, vol. 22, no. 2, pp. 1027–1070, Dec. 2020.

[212] M. Thammawichai, S. P. Baliyarasimhuni, E. C. Kerrigan, and J. B. Sousa, "Optimizing communication and computation for multi-UAV information gathering applications," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 54, no. 2, pp. 601–615, Apr. 2018.

[213] M. Kalinin, V. Krundyshev, and P. Zegzhda, "Cybersecurity risk assessment in smart city infrastructures," *Machines*, vol. 9, no. 4, p. 78, Apr. 2021.
[214] D. Wang, B. Bai, K. Lei, W. Zhao, Y. Yang, and Z. Han, "Enhancing information security via physical layer approaches in heterogeneous IoT with multiple access mobile edge computing in smart city," *IEEE Access*, vol. 7, pp. 54508–54521, 2019.
[215] H. Habibzadeh, B. H. Nussbaum, F. Anjomshoa, B. Kantarci, and T. Soyata, "A survey on cybersecurity, data privacy, and policy issues in cyber-physical system deployments in smart cities," *Sustain. Cities Soc.*, vol. 50, Oct. 2019, Art. no. 101660.
[216] F. Laamarti, H. F. Badawi, Y. Ding, F. Arafsha, B. Hafidh, and A. El Saddik, "An ISO/IEEE 11073 standardized digital twin framework for health and well-being in smart cities," *IEEE Access*, vol. 8, pp. 105950–105961, 2020.
[217] P.-Y. Kong, "Cellular-assisted device-to-device communications for healthcare monitoring wireless body area networks," *IEEE Sensors J.*, vol. 20, no. 21, pp. 13139–13149, Nov. 2020.
[218] Y. Zhang, L. Sun, H. Song, and X. Cao, "Ubiquitous WSN for healthcare: Recent advances and future prospects," *IEEE Internet Things J.*, vol. 1, no. 4, pp. 311–318, Aug. 2014.
[219] M. Rezaei, H. Noori, M. M. Razlighi, and M. Nickray, "ReFOCUS+: Multi-layers real-time intelligent route guidance system with congestion detection and avoidance," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 1, pp. 50–63, Jan. 2021.
[220] C. Roman, R. Liao, P. Ball, S. Ou, and M. de Heaver, "Detecting on-street parking spaces in smart cities: Performance evaluation of fixed and mobile sensing systems," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 7, pp. 2234–2245, Jul. 2018.
[221] J. Ferdous, M. P. Mollah, M. A. Razzaque, M. M. Hassan, A. Alamri, G. Fortino, and M. Zhou, "Optimal dynamic pricing for trading-off user utility and operator profit in smart grid," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 50, no. 2, pp. 455–467, Feb. 2020.
[222] A. Jindal, G. S. S. Aujla, N. Kumar, and M. Villari, "GUARDIAN: Blockchain-based secure demand response management in smart grid system," *IEEE Trans. Services Comput.*, vol. 13, no. 4, pp. 613–624, Jul./Aug. 2020.
[223] S. Cui, Y.-W. Wang, Y. Shi, and J.-W. Xiao, "A new and fair peer-to-peer energy sharing framework for energy buildings," *IEEE Trans. Smart Grid*, vol. 11, no. 5, pp. 3817–3826, Sep. 2020.
[224] X. Fu, D. Yang, Q. Guo, and H. Sun, "Security analysis of a park-level agricultural energy network considering agrometeorology and energy meteorology," *CSEE J. Power Energy Syst.*, vol. 6, no. 3, pp. 743–748, Sep. 2020.
[225] FAP. (2009). *The State of Food and Agriculture*. Accessed: Aug. 11, 2021. [Online]. Available: http://www.fao.org/3/i0680e/i0680e.pdf
[226] M. Torky and A. E. Hassanein, "Integrating blockchain and the Internet of Things in precision agriculture: Analysis, opportunities, and challenges," *Comput. Electron. Agricult.*, vol. 178, Nov. 2020, Art. no. 105476.
[227] L. Colizzi, D. Caivano, C. Ardito, G. Desolda, A. Castrignanò, M. Matera, R. Khosla, D. Moshou, K.-M. Hou, F. Pinet, J.-P. Chanet, G. Hui, and H. Shi, "Introduction to agricultural IoT," in *Agricultural Internet of Things and Decision Support for Precision Smart Farming*, A. Castrignanó, G. Buttafuoco, R. Khosla, A. M. Mouazen, D. Moshou, and O. Naud, Eds. London, U.K.: Academic, 2020, pp. 1–33, ch. 1.
[228] X. Yang, L. Shu, J. Chen, M. A. Ferrag, J. Wu, E. Nurellari, and K. Huang, "A survey on smart agriculture: Development modes, technologies, and security and privacy challenges," *IEEE/CAA J. Automat. Sinica*, vol. 8, no. 2, pp. 273–302, Feb. 2021.
[229] S. Giordano, "Innovative agriculture and sustainable food production. Applications of the Aquaponics system," in *Research and Innovation as Tools for Sustainable Agriculture, Food and Nutrition Security*, M. E. Moujabber, H. Belhouchette, M. Belkhodja, and P. Kalaitzis, Eds. Paris, France: OPTIONS méditerranéennes, 2018, pp. 75–81, ch. 2.
[230] E. Hofmann and M. Rüsch, "Industry 4.0 and the current status as well as future prospects on logistics," *Comput. Ind.*, vol. 89, pp. 23–34, Aug. 2020.
[231] G. Schuh, T. Potente, R. Varandani, C. Hausberg, and B. Fränken, "Collaboration moves productivity to the next level," *Proc. CIRP*, vol. 17, pp. 3–8, Jan. 2014.
[232] Y. Wu, H.-N. Dai, and H. Wang, "Convergence of blockchain and edge computing for secure and scalable IIoT critical infrastructures in industry 4.0," *IEEE Internet Things J.*, vol. 8, no. 4, pp. 2300–2317, Feb. 2021.
[233] P. C. Alcaraz, P. Y. Zhang, P. A. Cardenas, and P. L. Zhu, "Guest editorial: Special section on security and privacy in industry 4.0," *IEEE Trans. Ind. Informat.*, vol. 16, no. 10, pp. 6530–6531, Oct. 2020.
[234] G. Dalmarco, F. R. Ramalho, A. C. Barros, and A. L. Soares, "Providing industry 4.0 technologies: The case of a production technology cluster," *J. High Technol. Manage. Res.*, vol. 30, no. 2, Nov. 2019, Art. no. 100355.
[235] W. Saad, Z. Han, M. Debbah, A. Hjørungnes, and T. Basar, "Coalitional game theory for communication networks," *IEEE Signal Process. Mag.*, vol. 26, no. 5, pp. 77–97, May 2009.
[236] G. Yildirim and Y. Tatar, "Simplified agent-based resource sharing approach for WSN-WSN interaction in IoT/CPS projects," *IEEE Access*, vol. 6, pp. 78077–78091, 2018.
[237] M. J. Osborne, *An Introduction to Game Theory*. Oxford, U.K.: Oxford Univ. Press, 2004.
[238] K. Ritzberger, *Foundations of Non-Cooperative Game Theory*. Oxford, U.K.: Oxford Univ. Press, 2002.
[239] R. Branzei, D. Dimitrov, and S. Tijs, *Models in Cooperative Game Theory*. Berlin, Germany: Springer-Verlag, 2008.
[240] T. Başar and G. J. Olsder, *Dynamic Noncooperative Game Theory*. New York, NY, USA: Academic Press, 1982.
[241] R. S. Gibbons, *Game Theory for Applied Economics*. Princeton, NJ, USA: Princeton Univ. Press, 1992.
[242] D. Snidal, "The game theory of international politics," *World Politics*, vol. 38, no. 1, pp. 25–57, Oct. 1985.
[243] S. Mei, W. Wei, and F. Liu, "On engineering game theory with its application in power systems," *Control Theory Technol.*, vol. 15, no. 1, pp. 1–12, Jan. 2017.
[244] E. R. Weintraub, "Game theory and cold war rationality: A review essay," *J. Econ. Literature*, vol. 55, no. 1, pp. 148–161, Mar. 2017.
[245] M. Salarpour and A. Nagurney, "A multicountry, multicommodity stochastic game theory network model of competition for medical supplies inspired by the COVID-19 pandemic," *Int. J. Prod. Econ.*, vol. 236, Jun. 2021, Art. no. 108074.
[246] A. Panjaitan, "Application of game theory in determining the optimum marketing mix strategy in banking companies," *Int. J. Basic Appl. Sci.*, vol. 9, no. 2, pp. 53–57, Sep. 2020.
[247] B. M. Albaba and Y. Yildiz, "Modeling cyber-physical human systems via an interplay between reinforcement learning and game theory," *Annu. Rev. Control*, vol. 48, pp. 1–21, 2019.
[248] O. Compte and P. Jehiel, "The coalitional Nash bargaining solution," *Econometrica*, vol. 78, no. 5, pp. 1593–1623, Sep. 2010.
[249] R. B. Myerson, *Game Theory, Analysis of Conflict*. Cambridge, MA, USA: Harvard Univ. Press, 1991.
[250] G. Owen, *Game Theory*, 3rd ed. London, U.K.: Academic, 1995.
[251] E. Winter, "Chapter 53 the Shapley value," in *Handbook of Game Theory With Economic Applications*, vol. 3. North Holland, The Netherlands: Elsevier, 2002.
[252] A. E. Roth, "Lloyd Shapley (1923–2016)—A founding father of game theory," *Nature*, vol. 532, p. 178, Apr. 2016.
[253] A. Churkin, J. Bialek, D. Pozo, E. Sauma, and N. Korgin, "Review of cooperative game theory applications in power system expansion planning," *Renew. Sustain. Energy Rev.*, vol. 145, Jul. 2021, Art. no. 111056.
[254] M. Grabisch and Y. Funaki, "A coalition formation value for games in partition function form," *Eur. J. Oper. Res.*, vol. 221, no. 1, pp. 175–185, Aug. 2012.
[255] L. Zhou, K. Lü, P. Yang, L. Wang, and B. Kong, "An approach for overlapping and hierarchical community detection in social networks based on coalition formation game theory," *Expert Syst. Appl.*, vol. 42, no. 24, pp. 9634–9646, Dec. 2015.
[256] W. Saad, Z. Han, T. Basar, M. Debbah, and A. Hjorungnes, "Hedonic coalition formation for distributed task allocation among wireless agents," *IEEE Trans. Mobile Comput.*, vol. 10, no. 9, pp. 1327–1344, Sep. 2011.
[257] R. J. Aumann and J. H. Dreze, "Cooperative games with coalition structures," *Int. J. Game Theory*, vol. 3, no. 4, pp. 217–237, Dec. 1974.
[258] D. H. Nguyen, "Optimal solution analysis and decentralized mechanisms for peer-to-peer energy markets," *IEEE Trans. Power Syst.*, vol. 36, no. 2, pp. 1470–1481, Mar. 2021.
[259] M. I. Azim, W. Tushar, and T. K. Saha, "Coalition graph game-based P2P energy trading with local voltage management," *IEEE Trans. Smart Grid*, vol. 12, no. 5, pp. 4389–4402, Sep. 2021.
[260] T. Wang, L. Song, and Z. Han, "Coalitional graph games for popular content distribution in cognitive radio VANETs," *IEEE Trans. Veh. Technol.*, vol. 62, no. 8, pp. 4010–4019, Oct. 2013.

[261] R. B. Myerson, "Graphs and cooperation in games," *Math. Oper. Res.*, vol. 2, no. 3, pp. 225–229, Aug. 1977.
[262] C. Manuel, E. Ortega, and M. del Pozo, "Marginality and Myerson values," *Eur. J. Oper. Res.*, vol. 284, no. 1, pp. 301–312, Jul. 2020.
[263] X.-F. Hu, D.-F. Li, and G.-J. Xu, "Fair distribution of surplus and efficient extensions of the Myerson value," *Econ. Lett.*, vol. 165, pp. 1–5, Apr. 2018.
[264] R. B. Myerson, "Conference structures and fair allocation rules," *Int. J. Game Theory*, vol. 9, no. 3, pp. 169–182, Sep. 1980.
[265] S. R. Chatterjee, S. Ghosh, and M. Chakraborty, "Nash bargaining in resource allocation for cognitive radio: A review," *Wireless Pers. Commun.*, vol. 118, no. 1, pp. 125–139, Jan. 2021.
[266] J. F. Nash, "The bargaining problem," *Econometrica*, vol. 18, no. 2, pp. 155–162, 1950.
[267] C. Wei, Z. Shen, D. Xiao, L. Wang, X. Bai, and H. Chen, "An optimal scheduling strategy for peer-to-peer trading in interconnected microgrids based on RO and Nash bargaining," *Appl. Energy*, vol. 295, Aug. 2021, Art. no. 117024.
[268] Q. Ni and C. C. Zarakovitis, "Nash bargaining game theoretic scheduling for joint channel and power allocation in cognitive radio systems," *IEEE J. Sel. Areas Commun.*, vol. 30, no. 1, pp. 70–81, Jan. 2012.
[269] Y. Wang, X. Wang, C. Shao, and N. Gong, "Distributed energy trading for an integrated energy system and electric vehicle charging stations: A Nash bargaining game approach," *Renew. Energy*, vol. 155, pp. 513–530, Aug. 2020.
[270] H. Moulin, "Implementing the Kalai–Smorodinsky bargaining solution," *J. Econ. Theory*, vol. 33, no. 1, pp. 32–45, Jun. 1984.
[271] D. Karos, N. Muto, and S. Rachmilevitch, "A generalization of the egalitarian and the Kalai–Smorodinsky bargaining solutions," *Int. J. Game Theory*, vol. 47, no. 4, pp. 1169–1182, Jan. 2018.
[272] T. Başar, "Lecture notes on non-cooperative game theory," Hamilton Inst., Dublin, Ireland, Tech. Rep., Jul. 2010.
[273] W. Tushar, W. Saad, H. V. Poor, and D. B. Smith, "Economics of electric vehicle charging: A game theoretic approach," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 1767–1778, Dec. 2012.
[274] C. A. Holt and A. E. Roth, "The Nash equilibrium: A perspective," *Proc. Nat. Acad. Sci. USA*, vol. 101, no. 12, pp. 3999–4002, Mar. 2004.
[275] R. Song, Q. Wei, H. Zhang, and F. L. Lewis, "Discrete-time non-zero-sum games with completely unknown dynamics," *IEEE Trans. Cybern.*, vol. 51, no. 6, pp. 2929–2943, Jun. 2021.
[276] B. Luo, Y. Yang, and D. Liu, "Policy iteration Q-learning for data-based two-player zero-sum game of linear discrete-time systems," *IEEE Trans. Cybern.*, vol. 51, no. 7, pp. 3630–3640, Jul. 2021.
[277] C. M. de Melo and K. Terada, "The interplay of emotion expressions and strategy in promoting cooperation in the iterated prisoner's dilemma," *Sci. Rep.*, vol. 10, no. 1, p. 14959, Sep. 2020.
[278] A. Goldwaser and M. Thielscher, "Deep reinforcement learning for general game playing," in *Proc. AAAI Conf. Artif. Intell.*, New York, NY, USA, vol. 34, no. 2, Feb. 2020, pp. 1701–1708.
[279] Q. Dai, X. Xu, W. Guo, S. Huang, and D. Filev, "Towards a systematic computational framework for modeling multi-agent decision-making at micro level for smart vehicles in a smart world," *Robot. Auto. Syst.*, vol. 144, Oct. 2021, Art. no. 103859.
[280] W.-T. Lin, G. Chen, and C. Li, "Risk-averse energy trading among peer-to-peer based virtual power plants: A stochastic game approach," *Int. J. Electr. Power Energy Syst.*, vol. 132, Nov. 2021, Art. no. 107145.
[281] X. Liu, J. Zhang, P. Zhu, Q. Tan, and W. Yin, "Quantitative cyber-physical security analysis methodology for industrial control systems based on incomplete information Bayesian game," *Comput. Secur.*, vol. 102, Mar. 2021, Art. no. 102138.
[282] K. Akkarajitsakul, E. Hossain, and D. Niyato, "Distributed resource allocation in wireless networks under uncertainty and application of Bayesian game," *IEEE Commun. Mag.*, vol. 49, no. 8, pp. 120–127, Aug. 2011.
[283] M. Ghazvini, N. Movahedinia, K. Jamshidi, and N. Moghim, "Game theory applications in CSMA methods," *IEEE Commun. Surveys Tuts.*, vol. 15, no. 3, pp. 1062–1087, Nov. 2013.
[284] N. Liu, L. Zhou, C. Wang, X. Yu, and X. Ma, "Heat-electricity coupled peak load shifting for multi-energy industrial parks: A Stackelberg game approach," *IEEE Trans. Sustain. Energy*, vol. 11, no. 3, pp. 1858–1869, Jul. 2020.
[285] L. Chen, N. Liu, C. Li, and J. Wang, "Peer-to-peer energy sharing with social attributes: A stochastic leader–follower game approach," *IEEE Trans. Ind. Informat.*, vol. 17, no. 4, pp. 2545–2556, Apr. 2021.
[286] W. Tushar, B. Chai, C. Yuen, D. B. Smith, K. L. Wood, Z. Yang, and H. V. Poor, "Three-party energy management with distributed energy resources in smart grid," *IEEE Trans. Ind. Electron.*, vol. 62, no. 4, pp. 2487–2498, Apr. 2015.
[287] Q. Meng, Y. Liu, Z. Li, and C. Wu, "Dynamic reward and penalty strategies of green building construction incentive: An evolutionary game theory-based analysis," *Environ. Sci. Pollut. Res.*, vol. 28, no. 33, pp. 44902–44915, Apr. 2021.
[288] Y. Chen, D. Zhu, and L. Zhou, "A game theory analysis of promoting the spongy city construction at the building and community scale," *Habitat Int.*, vol. 86, pp. 91–100, Apr. 2019.
[289] Y. Song, S. Lee, Y. Choe, and S. A. Kim, "Collaborative design process for encouraging sustainable building design: A game theory-based approach," in *Cooperative Design, Visualization, and Engineering* (Lecture Notes in Computer Science), vol. 8091, Y. Luo, Ed. Berlin, Germany: Springer, 2013, pp. 19–26.
[290] B. Grzyl, M. Apollo, and A. Kristowski, "Application of game theory to conflict management in a construction contract," *Sustainability*, vol. 11, no. 7, p. 1983, Apr. 2019.
[291] Q. Shi, Y. Yan, J. Zuo, and T. Yu, "Objective conflicts in green buildings projects: A critical analysis," *Building Environ.*, vol. 96, pp. 107–117, Feb. 2016.
[292] L. Luo, X. Liang, C. Fang, Z. Wu, X. Wang, and Y. Wang, "How to promote prefabricated building projects through Internet of Things? A game theory-based analysis," *J. Cleaner Prod.*, vol. 276, Dec. 2020, Art. no. 124325.
[293] Z. Gou, "Human factors in green building: Building types and Users' needs," *MDPI Buildings*, vol. 9, no. 1, p. 17, Jan. 2019.
[294] J. Hao, D. W. Gao, and J. J. Zhang, "Reinforcement learning for building energy optimization through controlling of central HVAC system," *IEEE Open Access J. Power Energy*, vol. 7, pp. 320–328, 2020.
[295] E. Fernandez, M. J. Hossain, and M. S. H. Nizami, "Game-theoretic approach to demand-side energy management for a smart neighbourhood in Sydney incorporating renewable resources," *Appl. Energy*, vol. 232, pp. 245–257, Dec. 2018.
[296] X. Liang, Y. Peng, and G. Q. Shen, "A game theory based analysis of decision making for green retrofit under different occupancy types," *J. Cleaner Prod.*, vol. 137, pp. 1300–1312, Nov. 2016.
[297] B. Rajasekhar, N. Pindoriya, W. Tushar, and C. Yuen, "Collaborative energy management for a residential community: A non-cooperative and evolutionary approach," *IEEE Trans. Emerg. Topics Comput. Intell.*, vol. 3, no. 3, pp. 177–192, Jun. 2019.
[298] S. Cui, Y.-W. Wang, and J.-W. Xiao, "Peer-to-peer energy sharing among smart energy buildings by distributed transaction," *IEEE Trans. Smart Grid*, vol. 10, no. 6, pp. 6491–6501, Nov. 2019.
[299] A. Fleischhacker, H. Auer, G. Lettner, and A. Botterud, "Sharing solar PV and energy storage in apartment buildings: Resource allocation and pricing," *IEEE Trans. Smart Grid*, vol. 10, no. 4, pp. 3963–3973, Jul. 2019.
[300] W. Tushar, B. Chai, C. Yuen, S. Huang, D. B. Smith, H. V. Poor, and Z. Yang, "Energy storage sharing in smart grid: A modified auction-based approach," *IEEE Trans. Smart Grid*, vol. 7, no. 3, pp. 1462–1475, May 2016.
[301] C. P. Mediwaththe, E. R. Stephens, D. B. Smith, and A. Mahanti, "A dynamic game for electricity load management in neighborhood area networks," *IEEE Trans. Smart Grid*, vol. 7, no. 3, pp. 1329–1336, May 2016.
[302] D. Fisk, "Cyber security, building automation, and the intelligent building," *Intell. Buildings Int.*, vol. 4, no. 3, pp. 169–181, Jul. 2012.
[303] X. Cai, B. Wang, Z. Cao, H. Zhang, K. Han, M. Chen, J. Xu, C. Zi, and W. Wu, "Game control of attack and defense in cyber physical system," *Proc. Comput. Sci.*, vol. 187, pp. 488–494, Jan. 2021.
[304] K. Ding, X. Ren, H. Qi, G. Shi, X. Wang, and L. Shi, "Interference game for intelligent sensors in cyber–physical systems," *Automatica*, vol. 129, Jul. 2021, Art. no. 109668.
[305] H. Orojloo and M. A. Azgomi, "A game-theoretic approach to model and quantify the security of cyber-physical systems," *Comput. Ind.*, vol. 88, pp. 44–57, Jun. 2017.
[306] F. Miao, Q. Zhu, M. Pajic, and G. J. Pappas, "A hybrid stochastic game for secure control of cyber-physical systems," *Automatica*, vol. 93, pp. 55–63, Jul. 2018.

[307] P. Siano, G. De Marco, A. Rolan, and V. Loia, "A survey and evaluation of the potentials of distributed ledger technology for peer-to-peer transactive energy exchanges in local energy markets," *IEEE Syst. J.*, vol. 13, no. 3, pp. 3454–3466, Sep. 2019.

[308] K. Utkarsh, A. Trivedi, D. Srinivasan, and T. Reindl, "A consensus-based distributed computational intelligence technique for real-time optimal control in smart distribution grids," *IEEE Trans. Emerg. Topics Comput. Intell.*, vol. 1, no. 1, pp. 51–60, Feb. 2017.

[309] K. S. Wolske, K. T. Gillingham, and P. W. Schultz, "Peer influence on household energy behaviours," *Nature Energy*, vol. 5, no. 3, pp. 202–212, Jan. 2020.

[310] (Jul. 2021). Australian Renewable Energy Agency. *Demand Response*. Accessed: Oct. 5, 2021. [Online]. Available: https://arena.gov.au/renewable-energy/demand-response/

[311] D. Srinivasan, S. Rajgarhia, B. M. Radhakrishnan, A. Sharma, and H. P. Khincha, "Game-theory based dynamic pricing strategies for demand side management in smart grids," *Energy*, vol. 126, pp. 132–143, May 2017.

[312] R. Tang, S. Wang, and H. Li, "Game theory based interactive demand side management responding to dynamic pricing in price-based demand response of smart grids," *Appl. Energy*, vol. 250, pp. 118–130, Sep. 2019.

[313] M. Motalleb, A. Annaswamy, and R. Ghorbani, "A real-time demand response market through a repeated incomplete-information game," *Energy*, vol. 143, pp. 424–438, Jan. 2018.

[314] K. Jhala, B. Natarajan, and A. Pahwa, "Prospect theory-based active consumer behavior under variable electricity pricing," *IEEE Trans. Smart Grid*, vol. 10, no. 3, pp. 2809–2819, May 2019.

[315] W. Tushar, T. K. Saha, C. Yuen, D. Smith, P. Ashworth, H. V. Poor, and S. Basnet, "Challenges and prospects for negawatt trading in light of recent technological developments," *Nat. Energy*, vol. 5, pp. 834–841, Aug. 2020.

[316] M. I. Azim, W. Tushar, and T. K. Saha, "Cooperative negawatt P2P energy trading for low-voltage distribution networks," *Appl. Energy*, vol. 299, Oct. 2021, Art. no. 117300.

[317] C. Feng, F. Wen, S. You, Z. Li, F. Shahnia, and M. Shahidehpour, "Coalitional game-based transactive energy management in local energy communities," *IEEE Trans. Power Syst.*, vol. 35, no. 3, pp. 1729–1740, May 2020.

[318] W. Zhao, H. Diao, P. Li, X. Lv, E. Lei, Z. Mao, and W. Xue, "Transactive energy-based joint optimization of energy and flexible reserve for integrated electric-heat systems," *IEEE Access*, vol. 9, pp. 14491–14503, 2021.

[319] G. Tsaousoglou, P. Pinson, and N. G. Paterakis, "Transactive energy for flexible prosumers using algorithmic game theory," *IEEE Trans. Sustain. Energy*, vol. 12, no. 3, pp. 1571–1581, Jul. 2021.

[320] F. Nematkhah, S. Bahrami, F. Aminifar, and J. P. S. Catalao, "Exploiting the potentials of HVAC systems in transactive energy markets," *IEEE Trans. Smart Grid*, vol. 12, no. 5, pp. 4039–4048, Sep. 2021.

[321] L. Orihuela, P. Millán, and Á. R. del Nozal, "A non-cooperative game-theoretic approach for distributed voltage regulation in DC grids with a high penetration of renewable energies," *Electronics*, vol. 10, no. 7, p. 768, Mar. 2021.

[322] X. Yang, G. Wang, H. He, J. Lu, and Y. Zhang, "Automated demand response framework in ELNs: Decentralized scheduling and smart contract," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 50, no. 1, pp. 58–72, Jan. 2020.

[323] F. Luo, Z. Y. Dong, G. Liang, J. Murata, and Z. Xu, "A distributed electricity trading system in active distribution networks based on multi-agent coalition and blockchain," *IEEE Trans. Power Syst.*, vol. 34, no. 5, pp. 4097–4108, Sep. 2019.

[324] W. El-Baz, P. Tzscheutschler, and U. Wagner, "Integration of energy markets in microgrids: A double-sided auction with device-oriented bidding strategies," *Appl. Energy*, vol. 241, pp. 625–639, May 2019.

[325] W. Tushar, T. K. Saha, C. Yuen, P. Liddell, R. Bean, and H. V. Poor, "Peer-to-peer energy trading with sustainable user participation: A game theoretic approach," *IEEE Access*, vol. 6, pp. 62932–62943, 2018.

[326] Z. Li, J. Kang, R. Yu, D. Ye, Q. Deng, and Y. Zhang, "Consortium blockchain for secure energy trading in industrial Internet of Things," *IEEE Trans. Ind. Informat.*, vol. 14, no. 8, pp. 3690–3700, Aug. 2018.

[327] D. Smith, P. Wang, M. Ding, J. Chan, B. Spak, X. Guan, P. Tyler, T. Rakotoarivelo, Z. Lin, and T. Abbasi, "Privacy-preserved optimal energy trading, statistics, and forecasting for a neighborhood area network," *Computer*, vol. 53, no. 5, pp. 25–34, May 2020.

[328] M. Sheha, K. Mohammadi, and K. Powell, "Solving the duck curve in a smart grid environment using a non-cooperative game theory and dynamic pricing profiles," *Energy Convers. Manage.*, vol. 220, Sep. 2020, Art. no. 113102.

[329] G. El Rahi, S. R. Etesami, W. Saad, N. B. Mandayam, and H. V. Poor, "Managing price uncertainty in prosumer-centric energy trading: A prospect-theoretic Stackelberg game approach," *IEEE Trans. Smart Grid*, vol. 10, no. 1, pp. 702–713, Jan. 2019.

[330] P. Huang and Y. Sun, "A collaborative demand control of nearly zero energy buildings in response to dynamic pricing for performance improvements at cluster level," *Energy*, vol. 174, pp. 911–921, May 2019.

[331] B. Barabadi and M. H. Yaghmaee, "A new pricing mechanism for optimal load scheduling in smart grid," *IEEE Syst. J.*, vol. 13, no. 2, pp. 1737–1746, Jun. 2019.

[332] A. M. Jadhav, N. R. Patne, and J. M. Guerrero, "A novel approach to neighborhood fair energy trading in a distribution network of multiple microgrid clusters," *IEEE Trans. Ind. Electron.*, vol. 66, no. 2, pp. 1520–1531, Feb. 2019.

[333] C. Stevanoni, Z. De Greve, F. Vallee, and O. Deblecker, "Long-term planning of connected industrial microgrids: A game theoretical approach including daily peer-to-microgrid exchanges," *IEEE Trans. Smart Grid*, vol. 10, no. 2, pp. 2245–2256, Mar. 2019.

[334] Y. Yu, G. Li, and Z. Li, "A game theoretical pricing mechanism for multi-microgrid energy trading considering electric vehicles uncertainty," *IEEE Access*, vol. 8, pp. 156519–156529, 2020.

[335] O. Samuel, N. Javaid, A. Khalid, W. Z. Khan, M. Y. Aalsalem, M. K. Afzal, and B.-S. Kim, "Towards real-time energy management of multi-microgrid using a deep convolution neural network and cooperative game approach," *IEEE Access*, vol. 8, pp. 161377–161395, 2020.

[336] J. Suh and S.-G. Yoon, "Profit-sharing rule for networked microgrids based on Myerson value in cooperative game," *IEEE Access*, vol. 9, pp. 5585–5597, 2021.

[337] X. Dong, X. Li, and S. Cheng, "Energy management optimization of microgrid cluster based on multi-agent-system and hierarchical Stackelberg game theory," *IEEE Access*, vol. 8, pp. 206183–206197, 2020.

[338] F. S. Gazijahani and J. Salehi, "Game theory based profit maximization model for microgrid aggregators with presence of EDRP using information gap decision theory," *IEEE Syst. J.*, vol. 13, no. 2, pp. 1767–1775, Jun. 2019.

[339] E. Mojica-Nava, C. A. Macana, and Y. Quijano, "Dynamic population games for optimal dispatch on hierarchical microgrid control," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 44, no. 3, pp. 306–317, Mar. 2014.

[340] E. Mojica-Nava, C. Barreto, and N. Quijano, "Population games methods for distributed control of microgrids," *IEEE Trans. Smart Grid*, vol. 6, no. 6, pp. 2586–2595, Nov. 2015.

[341] F. Fang, Z. Zhu, S. Jin, and S. Hu, "Two-layer game theoretic microgrid capacity optimization considering uncertainty of renewable energy," *IEEE Syst. J.*, vol. 15, no. 3, pp. 4260–4271, Sep. 2021.

[342] Y. Fu, Z. Zhang, Z. Li, and Y. Mi, "Energy management for hybrid AC/DC distribution system with microgrid clusters using non-cooperative game theory and robust optimization," *IEEE Trans. Smart Grid*, vol. 11, no. 2, pp. 1510–1525, Mar. 2020.

[343] C. Liu, K. T. Chau, D. Wu, and S. Gao, "Opportunities and challenges of vehicle-to-home, vehicle-to-vehicle, and vehicle-to-grid technologies," *Proc. IEEE*, vol. 101, no. 11, pp. 2409–2427, Nov. 2013.

[344] X. Chen and K.-C. Leung, "Non-cooperative and cooperative optimization of scheduling with vehicle-to-grid regulation services," *IEEE Trans. Veh. Technol.*, vol. 69, no. 1, pp. 114–130, Jan. 2020.

[345] S. Xia, F. Lin, Z. Chen, C. Tang, Y. Ma, and X. Yu, "A Bayesian game based vehicle-to-vehicle electricity trading scheme for blockchain-enabled Internet of Vehicles," *IEEE Trans. Veh. Technol.*, vol. 69, no. 7, pp. 6856–6868, Jul. 2020.

[346] L. Banjanovic-Mehmedovic, E. Halilovic, I. Bosankic, M. Kantardzic, and S. Kasapovic, "Autonomous vehicle-to-vehicle (V2V) decision making in roundabout using game theory," *Int. J. Adv. Comput. Sci. Appl.*, vol. 7, no. 8, pp. 292–298, 2016.

[347] A. Talebpour, H. S. Mahmassani, and S. H. Hamdar, "Modeling lane-changing behavior in a connected environment: A game theory approach," *Transp. Res. Proc.*, vol. 7, pp. 420–440, Jan. 2015.

[348] S. Cheng, L. Li, X. Chen, S.-N. Fang, X.-Y. Wang, X.-H. Wu, and W.-B. Li, "Longitudinal autonomous driving based on game theory for intelligent hybrid electric vehicles with connectivity," *Appl. Energy*, vol. 268, Jun. 2020, Art. no. 115030.

[349] M. Liwang, J. Wang, Z. Gao, X. Du, and M. Guizani, "Game theory based opportunistic computation offloading in cloud-enabled IoV," *IEEE Access*, vol. 7, pp. 32551–32561, 2019.

[350] N. Li, D. W. Oyler, M. Zhang, Y. Yildiz, I. Kolmanovsky, and A. R. Girard, "Game theoretic modeling of driver and vehicle interactions for verification and validation of autonomous vehicle control systems," *IEEE Trans. Control Syst. Technol.*, vol. 26, no. 5, pp. 1782–1797, Sep. 2018.

[351] S. Du, T. Huang, J. Hou, S. Song, and Y. Song, "FPGA based acceleration of game theory algorithm in edge computing for autonomous driving," *J. Syst. Archit.*, vol. 93, pp. 33–39, Feb. 2019.

[352] K.-H. Nam Bui and J. J. Jung, "Cooperative game-theoretic approach to traffic flow optimization for multiple intersections," *Comput. Electr. Eng.*, vol. 71, pp. 1012–1024, Oct. 2018.

[353] X. Ji, K. Yang, X. Na, C. Lv, and Y. Liu, "Shared steering torque control for lane change assistance: A stochastic game-theoretic approach," *IEEE Trans. Ind. Electron.*, vol. 66, no. 4, pp. 3093–3105, Apr. 2019.

[354] F. Camara, R. Romano, G. Markkula, R. Madigan, N. Merat, and C. Fox, "Empirical game theory of pedestrian interaction for autonomous vehicles," in *Proc. Int. Conf. Methods Techn. Behav. Res.*, Manchester, U.K., Jun. 2018, pp. 238–244.

[355] Y. Liu and H. Liang, "A discounted stochastic multiplayer game approach for Vehicle-to-Grid voltage regulation," *IEEE Trans. Veh. Technol.*, vol. 68, no. 10, pp. 9647–9659, Oct. 2019.

[356] Z. Zhou, B. Wang, M. Dong, and K. Ota, "Secure and efficient vehicle-to-grid energy trading in cyber physical systems: Integration of blockchain and edge computing," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 50, no. 1, pp. 43–57, Jan. 2020.

[357] A. Laha, B. Yin, Y. Cheng, L. X. Cai, and Y. Wang, "Game theory based charging solution for networked electric vehicles: A location-aware approach," *IEEE Trans. Veh. Technol.*, vol. 68, no. 7, pp. 6352–6364, Jul. 2019.

[358] R. Yu, J. Ding, W. Zhong, Y. Liu, and S. Xie, "PHEV charging and discharging cooperation in V2G networks: A coalition game approach," *IEEE Internet Things J.*, vol. 1, no. 6, pp. 578–589, Dec. 2014.

[359] X. Ye, Y. Zhang, Y. Ni, Q. Wang, and Y. Chen, "Motivational game-theoretic Vehicle-to-Vehicle energy trading in the smart grid," in *Proc. IEEE/CIC Int. Conf. Commun. China (ICCC Workshops)*, Chongqing, China, Aug. 2020, pp. 231–236.

[360] A. G. Jember, W. Xu, C. Pan, X. Zhao, and X.-C. Ren, "Game and contract theory-based energy transaction management for internet of electric vehicle," *IEEE Access*, vol. 8, pp. 203478–203487, 2020.

[361] Y. Wan, J. Qin, F. Li, X. Yu, and Y. Kang, "Game theoretic-based distributed charging strategy for PEVs in a smart charging station," *IEEE Trans. Smart Grid*, vol. 12, no. 1, pp. 538–547, Jan. 2021.

[362] C. Wu, H. Mohsenian-Rad, and J. Huang, "Vehicle-to-aggregator interaction game," *IEEE Trans. Smart Grid*, vol. 3, no. 1, pp. 434–442, Mar. 2012.

[363] T. G. Alghamdi, D. Said, and H. T. Mouftah, "Decentralized game-theoretic scheme for D-EVSE based on renewable energy in smart cities: A realistic scenario," *IEEE Access*, vol. 8, pp. 48274–48284, 2020.

[364] T. Zhao, Y. Li, X. Pan, P. Wang, and J. Zhang, "Real-time optimal energy and reserve management of electric vehicle fast charging station: Hierarchical game approach," *IEEE Trans. Smart Grid*, vol. 9, no. 5, pp. 5357–5370, Sep. 2018.

[365] K. Kaur, S. Garg, G. Kaddoum, S. H. Ahmed, F. Gagnon, and M. Atiquzzaman, "Demand-response management using a fleet of electric vehicles: An opportunistic-SDN-based edge-cloud framework for smart grids," *IEEE Netw.*, vol. 33, no. 5, pp. 46–53, Sep. 2019.

[366] P. K. D. Pramanik, G. Pareek, and A. Nayyar, "Security and privacy in remote healthcare: Issues, solutions, and standards," in *The Design and Manufacture of Medical Devices*, P. J. P. Davim, Ed. Oxford, U.K.: Woodhead Publishing, 2012, pp. 201–225, ch. 14.

[367] S. Misra and S. Sarkar, "Priority-based time-slot allocation in wireless body area networks during medical emergency situations: An evolutionary game-theoretic perspective," *IEEE J. Biomed. Health Informat.*, vol. 19, no. 2, pp. 541–548, Mar. 2015.

[368] A. Mukherjee, D. De, and S. K. Ghosh, "FogIoHT: A weighted majority game theory based energy-efficient delay-sensitive fog network for Internet of Health Things," *Internet Things*, vol. 11, Sep. 2020, Art. no. 100181.

[369] D. D. J. de Macedo, G. M. de Araújo, M. L. Dutra, S. T. Dutra, and Á. G. R. Lezana, "Toward an efficient healthcare CloudIoT architecture by using a game theory approach," *Concurrent Eng.*, vol. 27, no. 3, pp. 189–200, May 2019.

[370] F. V. Mendonça, M. Catalão-Lopes, R. T. Marinho, and J. R. Figueira, "Improving medical decision-making with a management science game theory approach to liver transplantation," *Omega*, vol. 94, Jul. 2020, Art. no. 102050.

[371] J. Zhou, J. Li, and X. Di, "A novel lossless medical image encryption scheme based on game theory with optimized ROI parameters and hidden ROI position," *IEEE Access*, vol. 8, pp. 122210–122228, 2020.

[372] L. Li, V. Muneeswaran, S. Ramkumar, G. Emayavaramban, and G. R. Gonzalez, "Metaheuristic FIR filter with game theory based compression technique—A reliable medical image compression technique for online applications," *Pattern Recognit. Lett.*, vol. 125, pp. 7–12, Jul. 2019.

[373] A. Torkaman, N. M. Charkari, and M. Aghaeipour, "An approach for leukemia classification based on cooperative game theory," *Anal. Cellular Pathol.*, vol. 34, no. 5, pp. 235–246, 2011.

[374] B. S. Raja and S. Asghar, "Disease classification in health care systems with game theory approach," *IEEE Access*, vol. 8, pp. 83298–83311, 2020.

[375] P. A. Orlando, R. A. Gatenby, and J. S. Brown, "Cancer treatment as a game: Integrating evolutionary game theory into the optimal control of chemotherapy," *Phys. Biol.*, vol. 9, no. 6, Nov. 2012, Art. no. 065007.

[376] K. Stankova, J. S. Brown, W. S. Dalton, and R. A. Gatenby, "Optimizing cancer treatment using game theory—A review," *JAMA Oncol.*, vol. 5, no. 1, pp. 96–103, Jan. 2019.

[377] S. Lo Piano, "Ethical principles in machine learning and artificial intelligence: Cases from the field and possible ways forward," *Hum. Social Sci. Commun.*, vol. 7, no. 1, pp. 1–7, Jun. 2020.

[378] C. Tarrant, M. Dixon-Woods, A. M. Colman, and T. Stokes, "Continuity and trust in primary care: A qualitative study informed by game theory," *Ann. Family Med.*, vol. 8, no. 5, pp. 440–446, Sep. 2010.

[379] J. Xie, Q. Qin, J. Lu, L. Yang, and M. Jiang, "Evaluation of network public opinion on the doctor-patient relationship based on evolutionary game theory," *IEEE Access*, vol. 8, pp. 197147–197157, 2020.

[380] A. H. Celdrán, M. G. Pérez, F. J. G. Clemente, and G. M. Pérez, "Sustainable securing of medical cyber-physical systems for the healthcare of the future," *Sustain. Comput., Informat. Syst.*, vol. 19, pp. 138–146, Sep. 2018.

[381] C. Esposito, O. Tamburis, X. Su, and C. Choi, "Robust decentralised trust management for the Internet of Things by using game theory," *Inf. Process. Manage.*, vol. 57, no. 6, Nov. 2020, Art. no. 102308.

[382] H. Moosavi and F. M. Bui, "Delay-aware optimization of physical layer security in multi-hop wireless body area networks," *IEEE Trans. Inf. Forensics Security*, vol. 11, no. 9, pp. 1928–1939, Sep. 2016.

[383] Y. Zeng, L. Zhang, G. Yao, and Y. Fang, "Analysis of current situation and influencing factor of medical disputes among different levels of medical institutions based on the game theory in Xiamen of China," *Med.*, vol. 97, no. 38, pp. vol. e12501, pp. 1–10, Sep. 2018.

[384] D. W. McFadden, M. Tsai, B. Kadry, and W. W. Souba, "Game theory: Applications for surgeons and the operating room environment," *Surgery*, vol. 152, no. 5, pp. 915–922, Nov. 2012.

[385] S. Priyan and P. Mala, "Optimal inventory system for pharmaceutical products incorporating quality degradation with expiration date: A game theory approach," *Oper. Res. Health Care*, vol. 24, Mar. 2020, Art. no. 100245.

[386] X. Fu, A. Presbitero, S. V. Kovalchuk, and V. V. Krzhizhanovskaya, "Coupling game theory and discrete-event simulation for model-based ambulance dispatching," *Proc. Comput. Sci.*, vol. 136, pp. 398–407, Jan. 2018.

[387] R. Zongwei, L. Chuanqing, and G. Haini, "Strategy on doctor resource sharing among hospitals composed regional medical association based on game theory," in *Proc. 3rd Int. Conf. Inf. Manage. (ICIM)*, Chengdu, China, Apr. 2017, pp. 274–278.

[388] H. Zhang and Q. Du, "Role of government and regulatory system of medical waste recycling and transportation based on game theory," in *Advances in Artificial Systems for Logistic Engineering*, vol. 82, Z. Hu, Q. Zhang, S. Petoukhov, and M. He, Eds. Cham, Switzerland: Springer, 2021, pp. 360–364.

[389] F. M. Burbano, A. Yao, N. Burish, M. Ingargiola, M. Freeman, J. Stock, and J. P. Taub, "Solving congestion in the plastic surgery match: A game theory analysis," *Plastic Reconstructive Surg.*, vol. 143, no. 2, pp. 634–639, Feb. 2019.
[390] R. Altawy and A. M. Youssef, "Security, privacy, and safety aspects of civilian drones: A survey," *ACM Trans. Cyber-Phys. Syst.*, vol. 1, no. 2, pp. 1–25, Apr. 2017.
[391] M. E. Mkiramweni, C. Yang, J. Li, and W. Zhang, "A survey of game theory in unmanned aerial vehicles communications," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 4, pp. 3386–3416, May 2019.
[392] I. A. Nemer, T. R. Sheltami, and A. S. Mahmoud, "A game theoretic approach of deployment a multiple UAVs for optimal coverage," *Transp. Res. A, Policy Pract.*, vol. 140, pp. 215–230, Oct. 2020.
[393] O. Thakoor, J. Garg, and R. Nagi, "Multiagent UAV routing: A game theory analysis with tight price of anarchy bounds," *IEEE Trans. Automat. Sci. Eng.*, vol. 17, no. 1, pp. 100–116, Jan. 2020.
[394] J. Kusyk, M. U. Uyar, K. Ma, E. Samoylov, R. Valdez, J. Plishka, S. E. Hoque, G. Bertoli, and J. Boksiner, "Artificial intelligence and game theory controlled autonomous UAV swarms," *Evol. Intell.*, vol. 14, no. 4, pp. 1775–1792, Jul. 2020, doi: 10.1007/s12065-020-00456-y.
[395] A. Trotta, M. Di Felice, F. Montori, K. R. Chowdhury, and L. Bononi, "Joint coverage, connectivity, and charging strategies for distributed UAV networks," *IEEE Trans. Robot.*, vol. 34, no. 4, pp. 883–900, Aug. 2018.
[396] Y. Sun and L. Fu, "Real-time game theory based artificial potential field method for multiple unmanned aerial vehicles path planning," in *Proc. Int. Tech. Meeting Inst. Navigat.*, Reston, VA, USA, Feb. 2018, pp. 521–528.
[397] M. Smyrnakis, H. Qu, and S. M. Veres, "Improving multi-robot coordination by game-theoretic learning algorithms," *Int. J. Artif. Intell. Tools*, vol. 27, no. 7, Nov. 2018, Art. no. 1860015.
[398] D. H. Stolfi, M. R. Brust, G. Danoy, and P. Bouvry, "UAV-UGV-UMV multi-swarms for cooperative surveillance," *Frontiers Robot. AI*, vol. 8, Feb. 2021, Art. no. 616950.
[399] W. Zha, J. Chen, and Z. Peng, "Dynamic multi-team antagonistic games model with incomplete information and its application to multi-UAV," *IEEE/CAA J. Automat. Sinica*, vol. 2, no. 1, pp. 74–84, Jan. 2015.
[400] J. Chen, Q. Wu, Y. Xu, N. Qi, T. Fang, and D. Liu, "Spectrum allocation for task-driven UAV communication networks exploiting game theory," *IEEE Wireless Commun.*, vol. 28, no. 4, pp. 174–181, Aug. 2021.
[401] J. S. Ng, W. Y. B. Lim, H.-N. Dai, Z. Xiong, J. Huang, D. Niyato, X.-S. Hua, C. Leung, and C. Miao, "Joint auction-coalition formation framework for communication-efficient federated learning in UAV-enabled Internet of vehicles," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 4, pp. 2326–2344, Apr. 2021.
[402] L. Ruan, J. Wang, J. Chen, Y. Xu, Y. Yang, H. Jiang, Y. Zhang, and Y. Xu, "Energy-efficient multi-UAV coverage deployment in UAV networks: A game-theoretic framework," *China Commun.*, vol. 15, no. 10, pp. 194–209, Oct. 2018.
[403] M.-A. Messous, S.-M. Senouci, H. Sedjelmaci, and S. Cherkaoui, "A game theory based efficient computation offloading in an UAV network," *IEEE Trans. Veh. Technol.*, vol. 68, no. 5, pp. 4964–4974, May 2019.
[404] H. Luan, Y. Xu, D. Liu, Z. Du, H. Qian, X. Liu, and X. Tong, "Energy efficient task cooperation for multi-UAV networks: A coalition formation game approach," *IEEE Access*, vol. 8, pp. 149372–149384, 2020.
[405] S. Lhazmir, O. A. Oualhaj, A. Kobbane, and J. Ben-Othman, "Matching game with no-regret learning for IoT energy-efficient associations with UAV," *IEEE Trans. Green Commun. Netw.*, vol. 4, no. 4, pp. 973–981, Dec. 2020.
[406] Z. Sun, Y. Liu, J. Wang, G. Li, C. Anil, K. Li, X. Guo, G. Sun, D. Tian, and D. Cao, "Applications of game theory in vehicular networks: A survey," *IEEE Commun. Surveys Tuts.*, vol. 23, no. 4, pp. 2660–2710, Aug. 2021, doi: 10.1109/COMST.2021.3108466.
[407] A. Sanjab, W. Saad, and T. Basar, "A game of drones: Cyber-physical security of time-critical UAV applications with cumulative prospect theory perceptions and valuations," *IEEE Trans. Commun.*, vol. 68, no. 11, pp. 6990–7006, Nov. 2020.
[408] J. Chen, C. Touati, and Q. Zhu, "A dynamic game approach to strategic design of secure and resilient infrastructure network," *IEEE Trans. Inf. Forensics Security*, vol. 15, pp. 462–474, 2020.
[409] M. Xu, Y. Chen, and W. Wang, "A two-stage game framework to secure transmission in two-tier UAV networks," *IEEE Trans. Veh. Technol.*, vol. 69, no. 11, pp. 13728–13740, Nov. 2020.
[410] B. Vundurthy and K. Sridharan, "Protecting an autonomous delivery agent against a vision-guided adversary: Algorithms and experimental results," *IEEE Trans. Ind. Informat.*, vol. 16, no. 9, pp. 5667–5679, Sep. 2020.
[411] A. Eldosouky, A. Ferdowsi, and W. Saad, "Drones in distress: A game-theoretic countermeasure for protecting UAVs against GPS spoofing," *IEEE Internet Things J.*, vol. 7, no. 4, pp. 2840–2854, Apr. 2020.
[412] A. Ferdowsi, A. Eldosouky, and W. Saad, "Interdependence-aware game-theoretic framework for secure intelligent transportation systems," *IEEE Internet Things J.*, vol. 8, no. 22, pp. 16395–16405, Nov. 2021, doi: 10.1109/JIOT.2020.3020899.
[413] Z. Lv, D. Chen, R. Lou, and Q. Wang, "Intelligent edge computing based on machine learning for smart city," *Future Gener. Comput. Syst.*, vol. 115, pp. 90–99, Feb. 2021.
[414] B. Wang, M. Li, X. Jin, and C. Guo, "A reliable IoT edge computing trust management mechanism for smart cities," *IEEE Access*, vol. 8, pp. 46373–46399, 2020.
[415] J. Chen, C. Hua, and C. Liu, "Considerations for better construction and demolition waste management: Identifying the decision behaviors of contractors and government departments through a game theory decision-making model," *J. Cleaner Prod.*, vol. 212, pp. 190–199, Mar. 2019.
[416] J. Yang, R. Long, H. Chen, and Q. Sun, "A comparative analysis of express packaging waste recycling models based on the differential game theory," *Resour., Conservation Recycling*, vol. 168, May 2021, Art. no. 105449.
[417] D. Chen, P. Wawrzynski, and Z. Lv, "Cyber security in smart cities: A review of deep learning-based applications and case studies," *Sustain. Cities Soc.*, vol. 66, Mar. 2021, Art. no. 102655.
[418] Z. Ni and S. Paul, "A multistage game in smart grid security: A reinforcement learning solution," *IEEE Trans. Neural Netw. Learn. Syst.*, vol. 30, no. 9, pp. 2684–2695, Sep. 2019.
[419] A. Ferdowsi, A. Sanjab, W. Saad, and N. B. Mandayam, "Game theory for secure critical interdependent gas-power-water infrastructure," in *Proc. Resilience Week (RWS)*, Wilmington, DE, USA, Sep. 2017, pp. 184–190.
[420] M. S. Abdalzaher and O. Muta, "A game-theoretic approach for enhancing security and data trustworthiness in IoT applications," *IEEE Internet Things J.*, vol. 7, no. 11, pp. 11250–11261, Nov. 2020.
[421] C. T. Do, N. H. Tran, C. Hong, C. A. Kamhoua, K. A. Kwiat, E. Blasch, S. Ren, N. Pissinou, and S. S. Iyengar, "Game theory for cyber security and privacy," *ACM Comput. Surv.*, vol. 50, no. 2, p. 30, Jun. 2017.
[422] A. Triantafyllou, D. C. Tsouros, P. Sarigiannidis, and S. Bibi, "An architecture model for smart farming," in *Proc. 15th Int. Conf. Distrib. Comput. Sensor Syst. (DCOSS)*, Santorini Island, Greece, May 2019, pp. 385–392.
[423] S. Moglewer, "A game theory model for agricultural crop selection," *Econometrica*, vol. 30, no. 2, pp. 253–266, Apr. 1962.
[424] X. Guan, Q. Du, W. Zhang, and B. Wang, "Study on the pricing of water rights transaction between irrigation water users based on cooperative game in China," *Water*, vol. 13, no. 12, p. 1672, Jun. 2021.
[425] D. Gupta, P. Bhatt, and S. Bhatt, "A game theoretic analysis for cooperative smart farming," in *Proc. IEEE Int. Conf. Big Data (Big Data)*, Atlanta, GA, USA, Dec. 2020, pp. 1–10.
[426] S. Cabrera, "Application of the game theory with perfect information to an agricultural company," *Agricult. Econ.*, vol. 59, pp. 1–7, Jan. 2013.
[427] Y. Bai, K. Fan, K. Zhang, X. Cheng, H. Li, and Y. Yang, "Blockchain-based trust management for agricultural green supply: A game theoretic approach," *J. Cleaner Prod.*, vol. 310, Aug. 2021, Art. no. 127407.
[428] A. A. Barati, H. Azadi, and J. Scheffran, "Agricultural land fragmentation in iran: Application of game theory," *Land Use Policy*, vol. 100, Jan. 2021, Art. no. 105049.
[429] S.-M. Hosseini-Motlagh, M. Johari, and R. Zirakpourdehkordi, "Grain production management to reduce global warming potential under financial constraints and time value of money using evolutionary game theory," *Int. J. Prod. Res.*, vol. 59, no. 17, pp. 5108–5129, Sep. 2021.
[430] M. V. Podimata and P. C. Yannopoulos, "Evolution of game theory application in irrigation systems," *Agricult. Agricult. Sci. Proc.*, vol. 4, pp. 271–281, Jan. 2015.
[431] I. Bogardi and F. Szidarovsky, "Application of game theory in water management," *Appl. Math. Model.*, vol. 1, no. 1, pp. 16–20, Jun. 1976.
[432] D. H. Negri, "The common property aquifer as a differential game," *Water Resour. Res.*, vol. 25, no. 1, pp. 9–15, Jan. 1989.

[433] F. Weissing and E. Ostrom, "Irrigation institutions and the games irrigators play: Rule enforcement without guards," in *Game Equilibrium Models II: Methods, Morals, Markets*, R. Selten, Ed. Berlin, Germany: Springer, 1991, pp. 188–262.
[434] K. R. Dattatray, "Agricultural irrigation mathematical modeling using game theory for next generation farming," *J. Emerg. Technol. Innov. Res.*, vol. 6, no. 5, pp. 283–292, May 2019.
[435] M. Chen, Y. Sun, B. Liu, B. Yan, X. Li, K. Lu, T. Ren, B. Ma, and Y. Tian, "Design and implementation of a novel Internet of Things irrigation system with a precision irrigation robot," in *Proc. IEEE Int. Conf. Real-time Comput. Robot. (RCAR)*, Xining, China, Jul. 2021, pp. 1008–1015.
[436] S. Hone, L. Crase, M. Burton, B. Cooper, V. Gandhi, M. Ashfaq, B. Lashari, and B. Ahmad, "Farmer cooperation in participatory irrigation in south asia: Insights from game theory," *Water*, vol. 12, no. 5, p. 1329, May 2020.
[437] J. Lee, B. Bagheri, and H.-A. Kao, "A cyber-physical systems architecture for industry 4.0-based manufacturing systems," *Manuf. Lett.*, vol. 3, pp. 18–23, Jan. 2015.
[438] E. V. Goudarzi, M. Houshmand, O. F. Valilai, V. Ghezavati, and S. Bamdad, "Equilibrial service composition model in cloud manufacturing (ESCM) based on non-cooperative and cooperative game theory for healthcare service equipping," *Peer J. Comput. Sci.*, vol. 7, pp. 1–21, Mar. 2021.
[439] M. Bhatia, "Intelligent system of game-theory-based decision making in smart sports industry," *ACM Trans. Intell. Syst. Technol.*, vol. 12, no. 3, p. 29, Jul. 2021.
[440] M. Bhatia, "Game theory based framework of smart food quality assessment," *Trans. Emerg. Telecommun. Technol.*, vol. 31, no. 12, pp. 1–25, Mar. 2020.
[441] L. Rogers and Y. Wang, "Understanding the impact of game theory on circular economy within the apparel industry," in *Advanced Manufacturing and Automation X*, vol. 737, Y. Wang, K. Martinsen, T. Yu, and K. Wang, Eds. Singapore: Springer, 2021, pp. 394–400.
[442] X. Chen, J. Cao, and S. Kumar, "Government regulation and enterprise decision in China remanufacturing industry: Evidence from evolutionary game theory," *Energy, Ecology Environ.*, vol. 6, no. 2, pp. 148–159, Apr. 2021.
[443] H. Chen, J. Wang, and Y. Miao, "Evolutionary game analysis on the selection of green and low carbon innovation between manufacturing enterprises," *Alexandria Eng. J.*, vol. 60, no. 3, pp. 2139–2147, Apr. 2021.
[444] J. Wu, G. Du, and R. J. Jiao, "Optimal postponement contracting decisions in crowdsourced manufacturing: A three-level game-theoretic model for product family architecting considering subcontracting," *Eur. J. Oper. Res.*, vol. 291, no. 2, pp. 722–737, Jun. 2021.
[445] M. Tavanayi, A. Hafezalkotob, and J. Valizadeh, "Cooperative cellular manufacturing system: A cooperative game theory approach," *Scientia Iranica*, vol. 28, no. 5, pp. 1–40, 2020, doi: 10.24200/sci.2020.50315.1629.
[446] D. Carlucci, P. Renna, S. Materi, and G. Schiuma, "Intelligent decision-making model based on minority game for resource allocation in cloud manufacturing," *Manage. Decis.*, vol. 58, no. 11, pp. 2305–2325, Apr. 2020.
[447] N. Zhang, Y. Yang, X. Wang, and X. Wang, "Game analysis on the evolution of decision-making of vaccine manufacturing enterprises under the government regulation model," *Vaccines*, vol. 8, no. 2, p. 267, May 2020.
[448] C. Yang, S. Lan, T. Lin, L. Wang, Z. Zhuang, and G. Q. Huang, "Transforming Hong Kong's warehousing industry with a novel business model: A game-theory analysis," *Robot. Comput.-Integr. Manuf.*, vol. 68, Apr. 2021, Art. no. 102073.
[449] W. Karwowski and W. Zhang, "The discipline of human factors and ergonomics," in *Handbook Hum. Factors Ergonom.*, 5th ed., G. Salvendy and W. Karwowski, Eds. Hoboken, NJ, USA: Wiley, Aug. 2021, pp. 3–38, ch. 1.
[450] V. S. Dasari, B. Kantarci, M. Pouryazdan, L. Foschini, and M. Girolami, "Game theory in mobile CrowdSensing: A comprehensive survey," *Sensors*, vol. 20, no. 7, p. 2055, Apr. 2020.
[451] G. S. Aujla, N. Kumar, M. Singh, and A. Y. Zomaya, "Energy trading with dynamic pricing for electric vehicles in a smart city environment," *J. Parallel Distrib. Comput.*, vol. 127, pp. 169–183, May 2019.
[452] R. Hernández, C. Cárdenas, and D. Muñoz, "Game theory applied to transportation systems in smart cities: Analysis of evolutionary stable strategies in a generic car pooling system," *Int. J. Interact. Design Manuf.*, vol. 12, no. 1, pp. 179–185, Feb. 2018.
[453] J. Guo, X. Ding, and W. Wu, "A blockchain-enabled ecosystem for distributed electricity trading in smart city," *IEEE Internet Things J.*, vol. 8, no. 3, pp. 2040–2050, Feb. 2021.
[454] K. Anoh, S. Maharjan, A. Ikpehai, Y. Zhang, and B. Adebisi, "Energy peer-to-peer trading in virtual microgrids in smart grids: A game-theoretic approach," *IEEE Trans. Smart Grid*, vol. 11, no. 2, pp. 1264–1275, Mar. 2020.
[455] M. Zhu, X.-Y. Liu, and X. Wang, "Joint transportation and charging scheduling in public vehicle systems—A game theoretic approach," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 8, pp. 2407–2419, Aug. 2018.
[456] Y. Hui, Z. Su, and T. H. Luan, "Unmanned era: A service response framework in smart city," *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 6, pp. 1–15, Jun. 2021, doi: 10.1109/TITS.2021.3058385.
[457] C.-K. Wu, "A game theory approach for assessing risk value and deploying search- and-rescue resources after devastating tsunamis," *Environ. Res.*, vol. 162, pp. 18–26, Apr. 2018.
[458] Z.-X. Zhang, L. Wang, and Y.-M. Wang, "An emergency decision making method for different situation response based on game theory and prospect theory," *Symmetry*, vol. 10, no. 10, p. 476, Oct. 2018.
[459] M. Zamanipour, "Fast- and-Secure state-estimation in dynamic-control over communication channels: A game-theoretical viewpoint," *IEEE Trans. Signal Inf. Process. Netw.*, vol. 6, pp. 645–655, 2020.
[460] S. H. Kim, "Choice model based analysis of consumer preference for drone delivery service," *J. Air Transp. Manage.*, vol. 84, May 2020, Art. no. 101785.
[461] D. He, S. Chan, and M. Guizani, "Drone-assisted public safety networks: The security aspect," *IEEE Commun. Mag.*, vol. 55, no. 8, pp. 218–223, Aug. 2017.
[462] D.-H. Shin and K.-M. Chung, "The effects of input modality and story-based knowledge on users' game experience," *Comput. Hum. Behav.*, vol. 68, pp. 180–189, Mar. 2017.
[463] D. Shin, "The actualization of meta affordances: Conceptualizing affordance actualization in the metaverse games," *Comput. Hum. Behav.*, vol. 133, Aug. 2022, Art. no. 107292.

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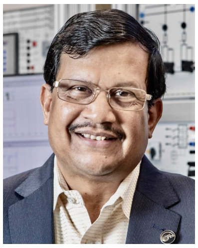

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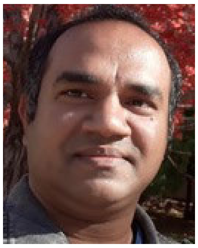

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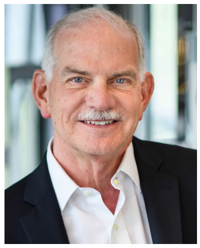

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