An Overview of IoT-Enabled Monitoring and Control Systems for Electric Vehicles

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As 5G technology becomes operational and continues to expand, smart cities become a reality that is transforming urban life at a rapid pace. Electric Vehicles (EV) and automated driving, equipped with Battery Energy Storage Systems (BESSs), are expected to dominate public transportation in smart cities. While new technologies can facilitate efficiency and reduce the costs in a city, they can also present challenges. This paper provides an overview of the technical challenges of real-time monitoring and control of Energy Storage Systems (ESSs) for EVs in smart cities. It also covers the Internet-of-the-Things (IoT) technology that can be utilized to address the challenges and improve the efficiency of Battery Management Systems (BMS). Autonomous Wireless Sensor Networks (WSNs) in smart cities provide the infrastructure to support advanced EV features, such as self-parking. IoT sensors can also be used to determine the State-of-Charge (SoC) in EVs by data-driven methods and cloud computing services.

Introduction

Energy consumption worldwide is on the rise without any sign of slowing down in the near future. Modern life relies heavily on transportation systems, communication networks, power stations, and other city infrastructure elements. Among technologies aimed at reducing the impact on the environment, Electric Vehicles (EVs) have become a focal point in the climate change discussion [1], [2]. EVs offer a far cleaner and greener means of transportation, but they present challenges concerning efficiency, energy storage, and energy management. Efficient energy storage is one of the major issues in smart grid [3]. Secure, fast, and reliable data collection must be achieved to yield optimum performance.

EV users are expected to have access to the features of vehicles and diagnostic information, notably the remaining battery charge referred to as the State-of-Charge (SoC). The device that handles this task is called the Battery Management System (BMS), which also evaluates the battery's State-of-Health (SoH), current, voltage, temperature, etc. A BMS processes a large amount of data to control the performance of a vehicle. Achieving a high energy density for Lithium-ion batteries requires fault detection and handling processes to ensure driver and vehicle safety. The Internet-of-the-Things (IoT) includes connected physical devices to share information. IoT networks make data maintenance, device monitoring, and system management more efficient.

Smart vehicles are being equipped with numerous sensors, and consumers are able to remotely communicate, monitor, and control their vehicles, thereby making all features normally fixed to the instrument panel available anywhere [4]. This is achieved by IoT actuators and smart sensors for real-time data transmission [5], [6]. The transportation industry is expected to mitigate traffic congestion strategies through IoT-enabled services, such as automated parking systems [7], [8]. IoT technology also provides the hardware needed to facilitate energy exchange between Plug-in Hybrid Electric Vehicles (PHEVs) and local electrical utilities with lower power consumption, lower cost, and higher scalability [9], [10]. In IoT-enabled smart cities, EVs can act as energy sources to support the grid as parts of Vehicle-to-Grid (V2G) systems [11]–[15]. IoT technology can be utilized to improve energy management and reduce the negative impact on the environment without compromising the functionality and convenience of modern vehicles [6]. The IoT sensors commonly rely on IP-based protocols for communication [3]. Hence, the deployment of remote monitoring applications, such as smart EVs, requires fast, reliable, and secure internet connectivity [16], [17].

This paper presents IoT technologies to monitor and control Energy Storage Systems (ESSs) for EVs and provides an overview of such technologies in smart cities. The next section describes the IoT implementation in smart cities. IoT-based monitoring and control systems for EVs are discussed subsequently, and the final section of the paper presents conclusions.

IoT Implementation in Smart Cities

Mobile Charging Stations

The growing number of EVs has created concerns as to how energy should be distributed to consumers in an efficient

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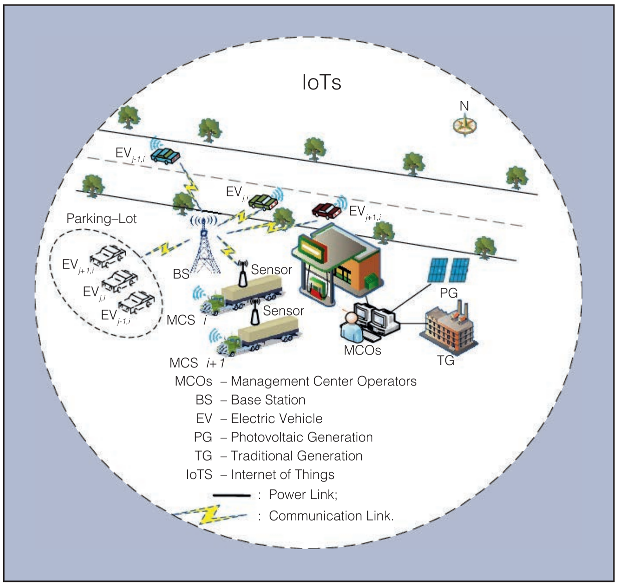

Fig. 1. The system model of an IoT-based MCS in a smart city [22].

and cost-effective manner. Mobile Charging Stations (MCSs) present a practical solution to the problem of efficient energy distribution for EVs [18]–[21]. MCSs can be used alongside the existing Fixed Charge Station (FCS) to ensure easy and reliable access to energy sources by EVs. MCSs can be relocated as needed to adapt to the emerging EV market. There are many challenges associated with the adoption of EVs by the transportation sector. For an FCS installation, utility upgrades are often needed to meet the power demand. Some municipal electrical infrastructure cannot make such accommodations, and hence, the EV market is restricted in those regions. Another advantage of MCSs is the ability to store energy at non-peak hours, thereby reducing the load demand on the local electrical utility [22].

IoT-collected data, such as the number of EVs, the charging state of their batteries, and the available power can be utilized to improve efficiency. If the power demand can be effectively monitored and forecasted, the impact of MCSs on the EV market becomes significant. Fig. 1 shows an example of an IoT-enabled MCS in a smart city.

Parking Systems

Parking management and traffic control, particularly in dense urban areas, have become a growing problem, resulting in considerable loss of time and revenue [7]. A promising solution to address the related challenges is to integrate and utilize IoT technology. A network of IoT sensors and data collection devices can provide the data needed to reduce congestion and maintain efficient traffic flow [8]. A secure, fast, and reliable parking system can be powered by an array of Wi-Fi Access Points (APs), local parking management servers, and a central server. Together, such devices provide information on parking availability and can reserve spots ahead of time for users, thereby reducing wait times. Wireless Sensor Networks (WSNs) are used to detect the presence or absence of a parked vehicle. A user can select a parking space based on the location, price, and availability. Fig. 2 shows an IoT-based parking system in a smart city.

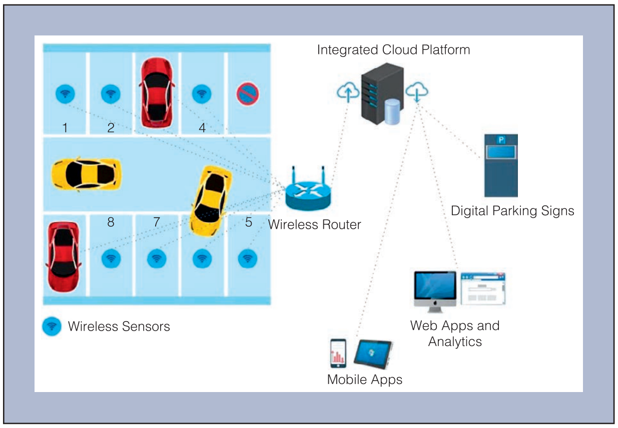

Fig. 2. The schematic of an IoT-based parking system in a smart city [8].

Public Safety Networks

The Third Generation Partnership Project Long Term Evolution, namely 3GPP-LTE, has become the principal structure for mobile message passing, including Public Safety Networks (PSNs) [23]–[25]. Such networks rely on centralized coordination, where a parent node distributes messages to all children nodes. The existing centralized networks are likely to remain the dominant PSN solution. However, decentralized networks play an important role in the emerging smart cities with IoT devices. If the operation of parent nodes (telecommunications tower, GSM satellite, or 5G antennas) in centralized networks is compromised, the PSNs become unreliable, leaving the public vulnerable. The potential solutions for PSNs are based on decentralized and self-organizing IoT networks that operate as a fail-safe mechanism for the Information Processing in Sensor Networks (IPSNs). The algorithms employed to control and manage such networks need to be optimized in terms of power consumption by IoT devices to meet the operational requirements for decentralized networks. For a design implementation, it is mandatory to adhere to the IPSN standards that govern performance measures, such as latency tolerance and data security [24], [25].

When a network is self-organized, a considerable amount of energy and data loss occurs. In addition, the lifespan of such networks must be taken into consideration. In such networks, the nodes are constantly changing their positions, and therefore, optimizing their topology for the least number of node hops or smallest displacement vector between nodes is not necessarily the most energy-efficient solution. In addition, such networks must be scalable so that they can be used in both dense urban areas as well as rural environments. One solution is to build a virtual backbone with a cluster of children nodes [26], [27], where the children nodes of Connected-Dominated Sets (CDSs) handle high network traffics. The CDSs allow device-specific information to pass quickly to smaller nodes [28]. Another promising approach developed to maximize

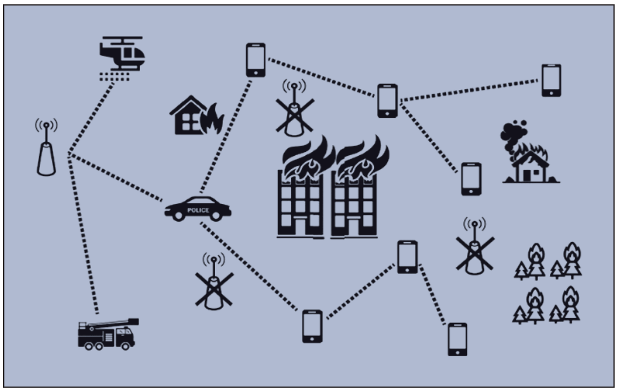

Fig. 3. The IoT-based PSN in a smart city [29].

energy efficiency is to utilize smart nodes in a tree-based topology. In such a network, the message packets are considered as noise until verified by a receiver node. The forwarded messages propagate throughout the network, and each message is delivered multiple times to receiver nodes offering a level of redundancy. Physical obstructions in the signal's path, i.e., buildings, trees, etc., can be circumvented as long as the node density in the region is adequate.

Smart cities deploy millions of battery-operated IoT devices that involve not only the classical centralized communication networks but also self-organizing autonomous networks. Many studies conducted on such networks show that Self-Organizing Tree (SOT) along with virtual backbone structures offer the most promising results in the interest of energy savings. Upon further inspection, a dense network consisting of many interconnected devices saves energy more than a network comprised of few devices. Energy efficiency and power consumption have a considerable impact on how future devices stay interconnected in smart cities. Fig. 3 shows an IoT-based PSN comprising several nodes interconnected in a tree.

EV Charging Stations

IoT is providing an efficient solution to the charging related issues linked with EVs. Several studies have been conducted to observe the impact of IoT incorporation in EVs [30]. Modern EVs are equipped with Lithium-ion batteries, which have a very high energy density, long life, and can be used more efficiently than their predecessors. The results of overcharging Lithium-ion batteries are known to be dangerous, causing toxic fumes, fire, and even explosion [31]. To avoid hazardous scenarios and to prolong battery life, a BMS is employed to monitor the characteristics of the battery. SoH, SoC, and charging characteristics are derived from current, voltage, and temperature measurements for each cell in the battery. Such parameters are of interest during both charging and discharging cycles. During the charge cycle, the cell charge rates are regulated to ensure all cells are balanced. BMS also ensures that the current, voltage, and temperature of each cell fall within the predetermined upper and lower safety limits [30]. Passive balancing is the most common, cost-effective cell balancing method where resistance switching is used to approximate the required charge rate.

IoT-based Monitoring and Control Systems for EVs

Lithium-ion batteries offer many advantages over legacy battery technologies, such as Nickel Metal Hydride or Lead-Acid. Such advantages include higher energy density, low self-discharge rates, low maintenance, and no memory effect that are observed in other battery technologies. Due to their increased energy density, Lithium-ion batteries must be monitored to ensure proper operation. Cell current, voltage, and temperature must be maintained within safe limits. In a conventional Lithium-ion battery pack, the pack is segmented into clusters of battery cells, called modules. Each module has a respective Module Management System (MMS). Modules are usually connected in series and parallel to supply the appropriate amount of current and voltage for a given application. The parallel groups of modules are controlled by BMS and each BMS feeds back the master Battery Energy Storage System (BESS). As the information passes from cell voltage to MMS, and then to the BMS, and before arriving at the BMS for processing, noise and latency are of greater concern. When such a network is utilized in large-scale systems, such as public transportation, the challenges of routing data-lines through various devices, such as vehicles, become a complicated task to manage.

Monitoring and Control

In [31], a BMS is developed that can control the charging and discharging cycles of a battery pack consisting of four-cell Lithium Ferrite Phosphate ($LiFePO_4$) batteries. The proposed BMS uses IoT to improve efficiency and reliability. Moreover, it carries the feature of a passive balancing system that uses the Global System for Mobile Communications (GSM) module to transmit the readings of current, voltage, and temperature to a remote server. The battery cells are connected in a series of cells with 10 Ah capacity per cell, where the balancing current is kept at 360 mA. The battery pack is balanced at 12.8 V using passive balancing. The readings for charging and discharging current are observed separately. The cell voltage is continuously monitored through a BMS during the charging, and thus, overcharging is protected. The system transmits the measurements of current, voltage, temperature to the GSM module through the TTL UART line. This technique is also used in another IoT-enabled network, where a command infrastructure is utilized to cut off the charging and discharging from a remote server if required. The proposed design uses an 8-bit microprocessor to control the BMS and a 10-bit ADC embedded module to read the voltage values. The system operates in five different states [32] that are: the charging state, where the input voltage is higher than a set value; the relaxation state to the battery pack with the minimum current; the balancing state, in which the difference between battery voltage is more than 100 mV; the discharge state, where the input voltage is too low to charge a battery pack; and the critical state to turn off load outputs [33]. The data is sent to a remote sensor by a BMS, which helps the evaluation of balancing function and provides information concerning system availability. The results of the experiment in [31] show that IoT technology improves the remote-based control and monitoring of the system considerably. IoT technology provides a practical solution to overcome the battery charging and discharging related issues in EVs.

IoT cloud-based monitoring is also proposed to support the BESS network topology. Cloud-based monitoring can be utilized for devices in an expandable wireless network. New nodes can be accommodated without interrupting the flow of information. All systems under the aforementioned design are connected wirelessly, eliminating physical vulnerabilities while also adding a level of noise immunity for larger systems. Cloud-based monitoring also offers more storage and data analysis tools to detect defects and outliers within the vehicle battery pack. Certain software tools can flag abnormalities that may be related to the faulty condition of certain vehicle parts. For instance, if a mechanical problem causes a battery module to fail earlier than the rest, this defect can be detected using cloud-based monitoring software. The EV manufacturers can also be notified if any production defects exist within a particular model or if the overall design has a performance flaw. Manufacturers can use machine learning tools to diagnose and correct problems as they occur, allowing the industry to take a proactive approach to design and improvement. Various simulation models including electrical circuit, thermal, electro-mechanical, and BMS models can be applied to improve the performance of the traditional BESS design architecture.

Along with fault diagnosis and passenger safety, operational states, such as SoC calculations, can also be improved. SoC is often calculated using a variety of methods. The chemical method involves measuring the pH of the battery electrolyte. Measuring a battery's internal pressure is also proven to be useful in calculating SoC for Nickel Metal Hydride batteries. However, this method requires access to the battery's electrolyte. The current integration method, known as the Coulomb Counting method, involves integrating the measured device current drawn over time, yielding coulombs consumed. This requires the device to have an accurate reference point for the number of coulombs in a fully charged battery. This method is also more susceptible to errors in measurement that cause long-term drift and inaccurate SoC calculations. The voltage method plots the battery pack closed-circuit voltage and compares the data against known curves. The solution must then be corrected for temperature changes and the required current. Given that batteries are voltage sources, which by definition, are meant to maintain a constant voltage, ΔV measured by the system using a voltage method becomes increasingly difficult, particularly for the new generation of batteries.

Advanced techniques for SoC calculations involve using statistical filters, such as the Kalman filter, which incorporates the Coulomb Counting method with the voltage method to overcome the shortcomings of either of the two methods. With cloud-based battery monitoring and management, a larger database can be formed by cloud-based BMS or MMS networks. It is shown in [4] that commercially available cloud database services, such as Firebase/Google, and machine learning tools, such as Google OR-Tools, can be used to further enhance SoC estimation in cloud-enabled BESS networks. Such tools offer correction for battery performance and battery physical and chemical characteristics. It is apparent that with more data storage capacity and access to high-performance cloud computing, this method offers better SoC estimation. In [4], it is also reported that Lithium-ion batteries require a specially designed system to ensure maximum efficiency, reliability, and system safety. BMS usually supports module communication through wired systems. However, using wired networks adds to the complexity of certain issues, such as difficulty in manufacturing, increased wiring costs, and complex design procedures for battery packets due to isolation concerns. To minimize the wiring complexity in BMSs, research studies on Wireless Battery Management Systems (WBMSs) have been carried out. The WBMS not only minimizes the wiring complexity but also supports location positioning for battery modules [34]. Linear Technologies Corporation has introduced a WBMS with an embedded smart mesh, in which different nodes are wirelessly connected to their neighboring nodes. The main node in this system may be overloaded

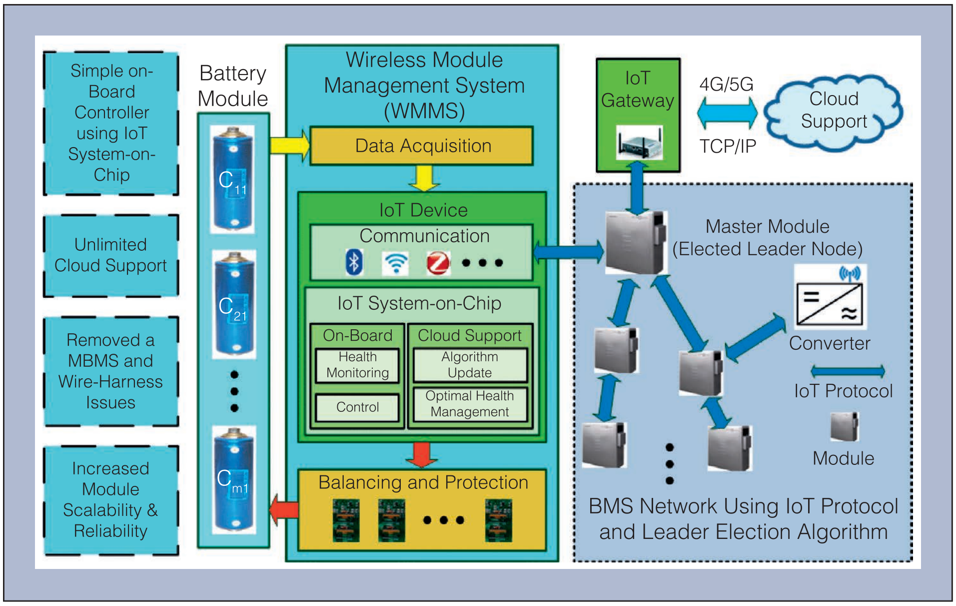

Fig. 4. The schematic of WBMS proposed by Linear Technologies Corporation [4].

due to multi-directional data collection, which can lead to the network slowdown. Fig. 4 shows the schematic of WBMS proposed by Linear Technologies Corporation.

It is mentioned in [4] that IoT can provide a reliable solution to the BMS problem. IoT devices containing a communication component and a system-on-chip Integrated Circuit (IC) form the central element of a WBMS. The communication subsystem uses IoT protocols and IoT gateways to communicate with external systems, such as the converter and the internal modules. The IC, which is used for balancing and data acquisition, measures the current, voltage, and temperature of battery cells at a given time and balances the voltage if required. In this method, the IoT nodes elect a leader module by executing a distributed algorithm. The leader node collects the data, which includes the battery power and available capacity of each module node, and sends the aggregated results to the converter to decide whether to continue or stop the battery charging process. The leader node is selected at a specific time through a unique algorithm, known as the Leader Election Algorithm (LEA), which is executed simultaneously by all nodes. Every node uses a random number to set a unique rank and reads the SoC of the current module. Then, the nodes broadcast the message over a communication medium and receive the message from other module nodes. Once the broadcast message is received, the nodes check the SoC value and the rank to elect a local leader in their communication range. Certain local leaders then repeat the same process and choose a global leader. Moreover, if the existing leader fails, other nodes can elect a new leader by re-executing the algorithm. The information about the new leader is then communicated to all other nodes. The leader node uses a special IoT protocol, called Message Queuing Telemetry Transport (MQTT), which helps to estimate the SoC of a battery bank. Furthermore, this protocol assists in module-to-module communication. It is expected that the IoT gateway can produce a large amount of data. Hence, it is important to store, process, and quickly aggregate the data. This method provides access to the cloud using various user interfaces. The data that is stored temporarily in the memory is sent to the cloud database, which uses different TCP/IP protocols. The proposed IoT wireless system supported by cloud-computing is quite efficient in managing a battery. It can minimize the wire-harness issues and provides higher battery module scalability.

Monitoring and Fault Diagnosis

The IoT technology along with cloud computing resources can potentially revolutionize the BMS as they are cost-effective and can efficiently determine the health of a battery. They are also adaptable and scalable and can ensure reliability and security in Lithium-ion BESSs [35]. In [35], the main goal is to design a cyber-physical BMS for Lithium-ion batteries by utilizing IoT sensors and cloud computing methods. The study incorporates WMMS and a platform for fault diagnosis. In the WMMS, IoT sensors measure the current, voltage, and temperature of a battery at a given time. As the nodes cannot store a large amount of data, the data is sent to a cloud server using TCP/IP protocol via an IoT gateway where the data is stored in a cloud data storage. The MMS, on the other hand, receives the results of health monitoring processes from the Cloud Battery Management Platform (CBMP). The CBMP is used to support the battery health monitoring system to detect any defects in battery cells. Fig. 5 shows the proposed CBMP for BESS in [35].

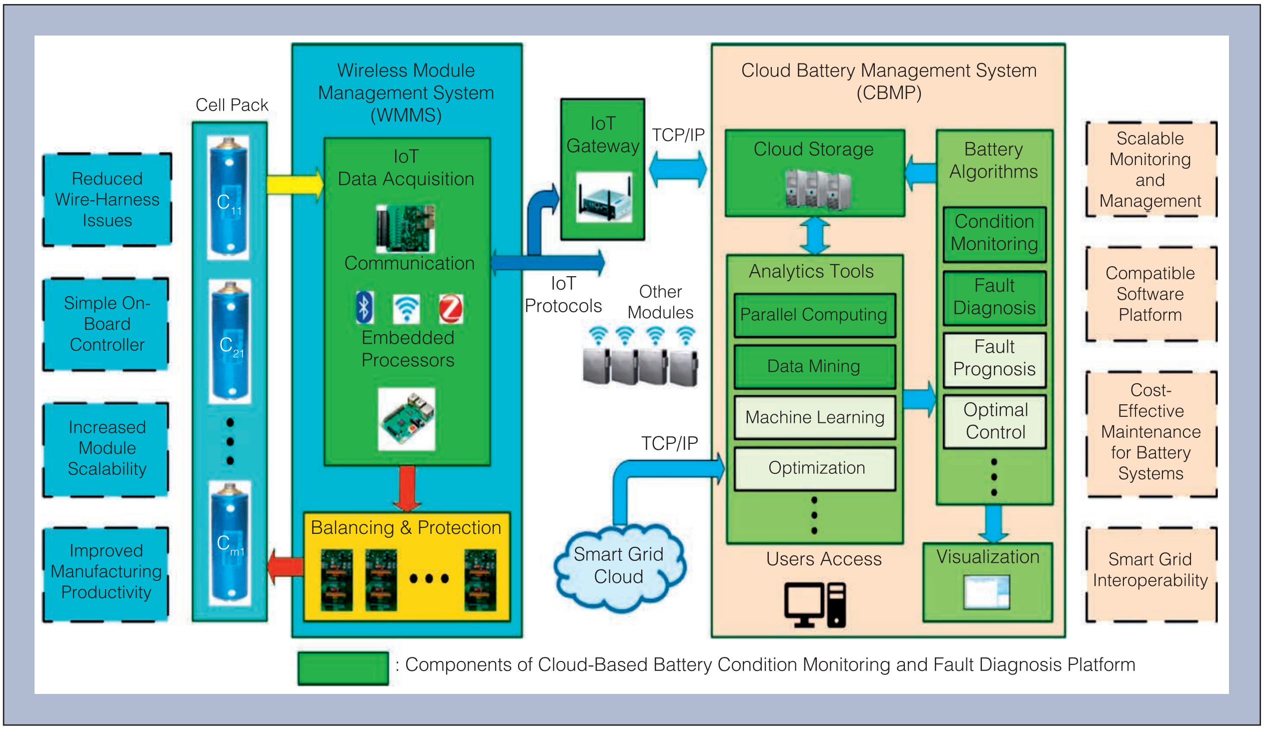

Fig. 5. The proposed CBMP for BESS in [35].

Energy Exchange

The development of IoT-enabled smart cities improves the power efficiency, security, and robustness of systems, and mitigates the negative environmental impacts [36]. Moving from traditional vehicles to EVs requires balancing between energy consumption and generation [37]. There is a growing interest in smaller shared and dispersed systems as a replacement for traditional large-scale ESSs. The emergence of PHEVs and EVs demands a robust and dynamic energy exchange system to replace the current utility model. EVs and PHEVs are capable of supplying energy back into the grid to alleviate power line congestion issues during peak hours. In [38], the impacts of ESSs on power grids are studies and it is indicated that IoT can provide a solution to ESS related issues. If EVs are charged by power grids at a mass-scale or during peak time, power grid congestion occurs, resulting in power outages and/or blackout. An advantage provided by EVs to the grid is the feature of Demand Response (DR), in which the EVs can inject power to the grid during peak hours by V2G capability to avoid power grid overload. EV charging is required to be continuously monitored to achieve grid balancing and minimize the risk of power failure [30]. To avoid the adverse impacts of mass charging of EVs on power grids, IoT technology can be utilized to determine the value of SoC and optimize EV charging while improving power grid stability.

Conclusions

In this paper, an overview of Internet-of-the-Things (IoT)-enabled monitoring and control of ESSs for EVs is investigated. IoT-related technologies continue to evolve and adapt to improve transportation and utility networks. Energy Storage Systems (ESSs) and optimization for utility grids and commercial Electric Vehicles (EVs) are greatly improved utilizing IoT sensors. IoT sensors are expected to be widely deployed in smart city infrastructure a large amount of data to manage EV charging schedules and ensure balanced and stable power grids. Various wireless charging techniques are discussed and compared, and IoT-enabled parking management and traffic control systems for smart cities are presented.

References

[1] F. Mohammadi, "Design, analysis, and electrification of a solar-powered electric vehicle," *J. Solar Energy Research*, vol. 3, no. 4, Dec. 2018.

[2] F. Mohammadi, "Hybridization of an electric vehicle using Lithium-ion batteries," in *Proc. 1st Int. Conf. Modern Approaches in Eng. Sci*, Nov. 2018.

[3] S. Rinaldi, F. Bonafini, P. Ferrari, A. Flammini, E. Sisinni, D. Di Cara, N. Panzavecchia, G. Tinè, A. Cataliotti, V. Cosentino, and S. Guaiana, "Characterization of IP-based communication for smart grid using software-defined networking," *IEEE Trans. Instrum. Meas.*, vol. 67, no. 10, Oct. 2018.

[4] T. Faika, T. Kim, and M. Khan, "An Internet of Things (IoT)-based network for dispersed and decentralized wireless battery management systems," in *Proc. 2018 IEEE Transportation Electrification Conf. Expo*, Jun. 2018.

[5] M. Bassoli, V. Bianchi, I. De Munari, and P. Ciampolini, "An IoT approach for an AAL Wi-Fi-based monitoring system," *IEEE Trans. Instrum. Meas.*, vol. 66, no. 12, Dec. 2017.

[6] A. Pötsch, A. Berger, and A. Springer, "Efficient analysis of power consumption behaviour of embedded wireless IoT systems," in *Proc. 2017 IEEE Int. Instrum. Meas. Technol. Conf.*, May 2017.

[7] F. Mohammadi, G.-A. Nazri, and M. Saif, "Modeling and simulation of hybrid electric vehicle using MATLAB/Simulink," in *Proc. 2019 Int. Conf. Power Generation Syst. Renewable Energy Technol.*, Aug. 2019.

[8] F. Mohammadi, G.-A. Nazri, and M. Saif, "A real-time cloud-based intelligent car parking system for smart cities," in *Proc. 2019 IEEE 2nd Int. Conf. Info. Comm. Signal Processing*, Sep. 2019.

[9] H. S. V. S. Kumar Nunna, S. Battula, S. Doolla, and D. Srinivasan, "Energy management in smart distribution systems with vehicle-to-grid integrated microgrids," *IEEE Trans. Smart Grid*, vol. 8, no. 5, Sep. 2018.

[10] M. Rizzi, A. Depari, P. Ferrari, A. Flammini, S. Rinaldi, and E. Sisinni, "Synchronization uncertainty versus power efficiency in LoRaWAN networks," *IEEE Trans. Instrum. Meas.*, vol. 68, no. 4, Apr. 2019.

[11] H.-T. Roh and J.-W. Lee, "Residential demand response scheduling with multiclass appliances in the smart grid," *IEEE Trans. Smart Grid*, vol. 7, no. 1, Jan. 2016.

[12] N. U. Hassan, Y. I. Khalid, C. Yuen, S. Huang, M. A. Pasha, K. L.Wood, and S. G. Kerk, "Framework for minimum user participation rate determination to achieve specific demand response management objectives in residential smart grids," *Int. J. Electrical Power Energy Syst*. vol. 74, Jan. 2016.

[13] E. C. Kara, J. S. Macdonald, D. Black, M. Bérges, G. Hug, and S. Kiliccote, "Estimating the benefits of electric vehicle smart charging at non-residential locations: a data-driven approach," *Applied Energy*, vol. 155, Oct. 2015.

[14] H. S. V. S. K. Nunna, and S, Doolla, "Demand response in smart distribution system with multiple microgrids," *IEEE Trans. Smart Grid*, vol. 3, no. 4, Dec. 2012.

[15] F. R. Islam and H. R. Pota, "V2G technology to improve wind power quality and stability," in *Proc. 2011 Australian Control Conf.*, Nov. 2011.

[16] S. C. Folea and G. D. Mois, "Lessons learned from the development of wireless environmental sensors," *IEEE Trans. Instrum. Meas.*, vol. 69, no. 6, Jun. 2020.

[17] L. Lombardo, S. Corbellini, M. Parvis, A. Elsayed, E. Angelini, and S. Grassini, "Wireless sensor network for distributed environmental monitoring," *IEEE Trans. Instrum. Meas.*, vol. 67, no. 5, May 2018.

[18] Y. Liu, Y. Xiang, Y. Tan, B. Wang, J. Liu, and Z. Yang, "Optimal allocation model for EV charging stations coordinating investor and user benefits," *IEEE Access*, vol. 6, Jun. 2018.

[19] W. Lee, R. Schober and V. W. S. Wong, "An analysis of price competition in heterogeneous electric vehicle charging stations," *IEEE Trans. Smart Grid*, vol. 10, no. 4, Jul. 2019.

[20] X. Duan, C. Zhao, S. He, P. Cheng, and J. Zhang, "Distributed algorithms to compute Walrasian equilibrium in mobile crowdsensing," *IEEE Trans. Ind. Electron.*, vol. 64, no. 5, May 2017.

[21] Z. Su, Q. Xu, J. Luo, H. Pu, Y. Peng, and R. Lu, "A secure content caching scheme for disaster backup in fog computing enabled

mobile social networks," *IEEE Trans. Ind. Informat*. vol. 14, no. 10, Oct. 2018.

[22] H. Chen, Z. Su, Y. Hui, and H. Hui, "Dynamic charging optimization for mobile charging stations in Internet of Things," *IEEE Access*, vol. 6, Sep. 2018.

[23] T. Doumi, M. F. Dolan, S. Tatesh, A. Casati, G. Tsirtsis, K. Anchan, and D. Flore, "LTE for public safety networks," *IEEE Commun. Mag*., vol. 51, no. 2, Feb. 2013.

[24] L. Xu, J. Xie, X. Xu, and S. Wang, "Enterprise LTE and WiFi interworking system and a proposed network selection solution," in *Proc. 2016 ACM/IEEE Symp. Architectures for Networking and Commun. Syst*., Mar. 2016.

[25] B. Singh, O. Tirkkonen, Z. Li, M. A. Uusitalo, and R. Wichman, "Selective multi-hop relaying for ultra-reliable communication in a factory Environment," in *Proc. 2016 IEEE 27th Ann. Int. Symp. Personal, Indoor, and Mobile Radio Commun*., Sep. 2016.

[26] B. Das and V. Bharghavan, "Routing in ad-hoc networks using minimum connected dominating sets," *Int. Conf. Commun*., Jun. 1997.

[27] P.-J. Wan, K. M. Alzoubi, and O. Frieder, "Distributed construction of connected dominating set in wireless ad hoc networks," *Mobile Networks Appl*., vol. 9, no. 2, Apr. 2004.

[28] J. Yu, N. Wang, G. Wang, and D. Yu, "Connected dominating sets in wireless ad hoc and sensor networks – a comprehensive survey," *Computer Commun*., vol. 36, no. 2, Jan. 2013.

[29] I. Sohn and S. H. Lee, "A message-passing approach to self-organizing Internet-of-Things based public safety networks," *IEEE Access*, vol. 6, Nov. 2018.

[30] F. Mohammadi, G.-A. Nazri, and M. Saif, "A bidirectional power charging control strategy for plug-in hybrid electric vehicles," *Sustainability*, vol. 11, no. 16, Aug. 2019.

[31] İ. Aydın and Ö. Üstün, "A basic battery management system design with IoT feature for LiFePO4 batteries," in *Proc. 2017 10th Int. Conf. Elec. Elect. Eng*., Nov.-Dec. 2017.

[32] H. Ibrahim, A. Ilinca, and J. Perron, "Energy storage systems—characteristics and comparisons," *Renewable and Sustainable Energy Rev*., vol. 12, no. 5, Jun. 2008.

[33] F. Mohammadi, "Design and electrification of an electric vehicle using Lithium-ion batteries," in *Proc. 3rd Int. Conf. Elec. Eng*., Oct. 2018.

[34] A. Dinger, R. Martin, X. Mosquet, D. Rizoulis, M. Russo, and G. Sticher, "Batteries for electric cars: challenges, opportunities, and the outlook to 2020," *The Boston Consulting Group*, Jan. 2010.

[35] T. Kim, D. Makwana, A. Adhikaree, J. S. Vagdoda, and Y. Lee, "Cloud-based battery Condition monitoring and fault diagnosis platform for large-scale Lithium-Ion battery energy storage systems," *Energies*, vol. 11, no. 1, Jan. 2018.

[36] X. Fang, S. Misra, G. Xue, and D. Yang, "Smart grid—the new and improved power grid: a survey," *IEEE Commun. Surveys Tutorials*, vol. 14, no. 4, Dec. 2011.

[37] B. P. Roberts and C. Sandberg, "The role of energy storage in development of smart grids," *Proc. IEEE*, vol. 99, no. 6, Jun. 2011.

[38] M. Asaad, F. Ahmad, M. S. Alam, and Y. Rafat, "IoT enabled electric vehicle's battery monitoring system," in *Proc. 1st EAI Int. Conf. Smart Grid Assisted Internet of Things*, Jul. 2017.

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