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Analysis of the applications of Lithium-ion batteries in Internet of Things (IoT) battery powered devices

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Abstract

Many Internet-of-Things (IoT) devices are powered by electrical grids whose supply of power is interrupted by critical grid failures which occurs due to the outbreak of natural disasters. The IoT device development which can operate during such scenarios must be designed with the best power energy source that can withstand the natural disasters menace. In this study Lithium-ion batteries are considered to evaluate its operation time, output power, and any general technical specifications. Currently, batteries are more cost-effective, however as the cost of fuel cells comes down, the higher power density will be valuable.

Keywords: **Lithium-ion battery, Internet-of-Things, battery power, power requirements**

I. Introduction

There is a trend of continuous growth of the Internet of Things (IoT) which has led to the development of different types of wireless sensors that are used for monitoring and actuation, communicating with each other and with various infrastructures through the Internet. The internet of things **(**IoT) is technology where a system of interrelated computing devices, mechanical and digital machines, objects, animals, and people are provided with unique identifiers (UIDs) and are able to produce, process, and transfer data over a network without requiring human-to-human or human-to-computer interaction [1][2]. IoT is a fast growing network of physical objects that have an internet protocol (IP) address for internet connectivity, and the communication that occurs between these objects and other internet enabled devices and systems. A thing in IoT can be a person, an animal, natural objects, or man-made objects that can be assigned an IP address ad is able to transfer data over a network. IoT has evolved over the recent past since its first mention in 1999 by Kevin Ashton, a co-founder of the Auto-ID centre at MIT [3]. IoT in general involves internet, wireless technologies, micro-services, and micro-electromechanical systems. The storage in the form of batteries has traditionally been the dominant source of power in wireless IoT systems. A lot of progress has been made on batteries as well as in other energy storage devices such as micro-fuel cells, micro-heat engines, and capacitors. However of them all the batteries and in particular the lithium-ion batteries (LIBs) are the dominant source of power in the IoT industry due to their miniaturization, high capacity, good temperature sensitivity, and less weight [4]. In order to survive for longer periods of time on a single battery charge, an IOT node should exhibit low power consumption [5]. In this paper the progress of LIBs technology will be evaluated, followed by the IoT devices and technology. The expectations, opportunities, and challenges of IoT is also examined.

II. LIB technology

Lithium-ion batteries (LIBs) have emerged as a promising energy storage solution for IoTs devices**.** The lifespan of LIBs in IoTs applications will largely depend on the progress of battery technology as well as usage patterns at the IoTs device level. Long battery lifespan will have a benefit of reducing the need for second, or even third battery replacement[6][7][8] when capacity drops by a given percentage of the original rated value, thereby reducing the cost of operating IoTs devices. Zhang et.al [9] notes that there are many aspects to the process of developing a battery management system, such as requirement analysis, modelling and simulation, control strategy research, and on-line hardware test, which all need a capable model to identify the characteristics of the lithium-ion batteries. Thus the LIBs technology is still under development, as more reliable and safer batteries have not been produced yet. Although literature [10] states that LIB technology is migrating from the portable electronics domain to larger-scale applications, the common denominator in the LIB technology is improvements in specific energy, power, safety, and reliability [11]. This means that the demand for better batteries is driven by many industries, and rechargeable LIBs has emerged as the dominant energy storage source for consumer electronics, automotive, aerospace, and stationary storage applications.

Different operating conditions such as fluctuations of the current, temperature, vibration, and SOC ranges make the LIB state to vary as it is a dynamic system. There are various models that are used for LIBs due to their simplicity, effectiveness, or accuracy. The equivalent circuit model (ECM) is applied for the modelling of batteries with the current and ambient temperatures as inputs, and voltages, current and SOC as the measured output. The ECM is a physics-based model that makes use of capacitors and resistors to represent the diffusion process and internal impedance of the battery cell respectively. The ECM will include the electro-thermal model, and to ensure the accuracy of state estimation, when the EKF is applied. The battery system is constructed and simulated using MATLAB/Simulink 2016a. For simplicity and effectiveness, the Thevenin equivalent circuit model is widely used in many real applications [15], while for the purpose of those applications which requires high accuracy the nth order Thevenin model is again widely used. The Thevenin equivalent circuit model which is used in this paper is shown in Figure 1.

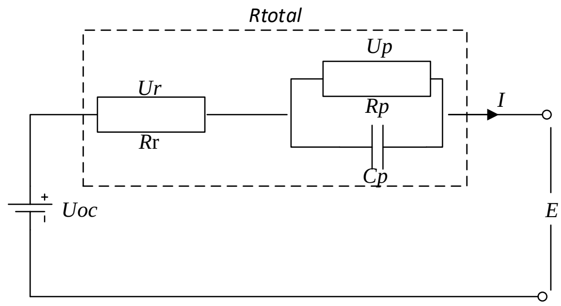

Figure 1. Thevenin equivalent circuit model

This model is commonly used by BMS for the estimation battery SOC and SOH diagnosis because it has high computational efficiency despite suffering from the challenge of low accuracy and low fidelity. In this research to typically estimate the hidden battery SOC, KF and EKF on the basis of the ECM, a time state-space model shown in Equation 1, is used.

$$\begin{cases} x_{k+1} = f(x_k, u_k) + w_k \\ y_k = g(x_k, u_k) + v_k \end{cases} \tag{1}$$

where x_k is the state vector to be estimated at the kth step, u_k is the system input vector (e.g. current), y_k is the output vector (e.g. the terminal voltage), w_k is the random process noise, $f(x_k,u_k)$ is the system state transition function, $g(x_k,u_k)$ is the system measurement function, assuming that k is the discrete-time index, and v_k is the measurement noise of the output vector. Since $f(x_k,u_k)$ and $g(x_k,u_k)$ are linearized y a first-order Taylor-series expansion with $f(\cdot)$ is the state transition function and $g(\cdot)$ is the ECM that relates the output vector with the input vector together with the hidden state vectors, w_k *and* v_k are non-zero mean white Gaussian stochastic processes with covariance matrices Σ_w and Σ_v. We assume that $f(x_k,u_k)$ and $g(x_k,u_k)$ are differentiable at all operating points (x_k,u_k).
where *Uoc* is the open-circuit voltage, *Ur* is the Ohmic voltage, *Rr* is the Ohmic resistance, *Up* is the polarization voltage, *Rp* is the equivalent polarization resistance, *Cp* is the Polarization capacitance, *E* is the terminal voltage, and *I* is the load current.

$$\begin{cases} U_p = -\frac{U_p}{C_p R_p} + \frac{I}{C_p} \\ E = U_{oc} - U_p - IR_o \end{cases} \quad (2)$$

There are commonly three categories of methods used to estimate the SOC namely non-model-based coulomb counting methods, the black-box battery model, and Kalman filtering-state-space battery models which comes with different merits and demerits [16]. The non-model-based coulomb counting method is adopted due to its simplicity, and being online. It is common for battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs), because it measures constant current and computes the accumulated charge to estimate the SOC. The battery SOC is calculated by integrating the load current to know how much capacity is used and remained [17]. The black-box methods describe the non-linear relationship between the battery SOC and its influencing factors like temperature [18], current [19], and vibrations [20] yielding into good SOC estimations. In this method there is no system state equation as the model accuracy is closely related to the training data and training methods as the model is established by training and learning experimental data [12]. The Kalman filtering methods are self-corrected, online and provides dynamic SOC estimation error range with high accuracy but comes with high computational costs but are popular for real-time battery management [21][22]. There are many extensions of Kalman filtering and each has its own merits. The total accuracy of SOC estimation for any EKF-based methods is directly affected by the precision of the battery model. The input and output parameters of the LIB model is shown in Figure 2.

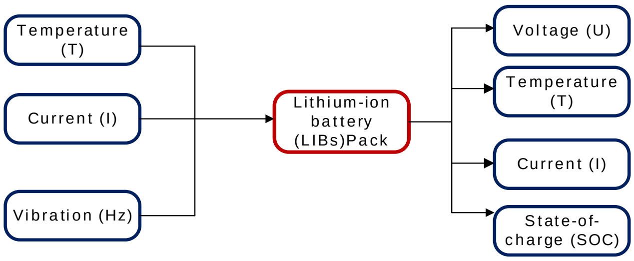

Figure 2. Input/output parameters of LIB model

From Figure 2, the input parameters are temperature, currents, and vibrations which when simulated yields the results for voltage, temperature, currents, and SOC values. The input current is constant always during charging and discharging [23], while the output current will keep changing as other parameter like temperature, and vibrations that are induced to the battery changes. When the input current is positive it indicates that the battery is charging and when the current is negative sign it indicates that the battery is discharging. In experimental or simulation setup the input current, vibration, and temperature are treated as independent quantities that are controlled fully. During charging, the battery cells current is controlled in a way that to ensure that the negative potential is maintained constantly above 0 V, and the charging current has to be reduces over the battery lifetime to avoid accelerated aging. The EV acceleration and deceleration has randomness which produces the LB output current which corresponds to the random changes. This output current plays a very big role in the determination of the losses inside a battery and is an important parameter to consider when analyzing the performance of batteries. The temperature in the temperature chamber, together with vibrational frequency should be varied to observe the behaviour of the battery. The results of the battery model is the battery voltage, current, temperature, and SOC.

III. IoT Technology

The Internet of Things phenomenon is allowing the collection of data from sensor nodes practically anywhere in the environment, and giving non-electronic objects the ability to communicate, opening up a whole new sphere of applications for electronic systems. Selecting batteries for Internet of Things connected systems can be tricky, as there is such a wide variety of application types. The IoT is an emerging technology, encompassing a wide spectrum of applications related to industrial control, smart campus[12][13],smart metering, smart transport, smart home automation, smart agriculture, smart eHealth and so on [14][15][16], wherein the devices involved run long hours under strict energy constraints. This IoT technology can be deployed in any field as it is an enabler of reaching out into the real world of physical objects [17]. Technologies like Radio Frequency Identification (RFID), short-range wireless communications, real-time localization, long-range (LORA) networks, and sensor networks becoming increasingly pervasive, making the IoT a reality.

The IoT system contains four main components which includes the sensing components, connectivity or communication components, data processing and cloud component, and the user services or interface and applications [18]. The sensor component in IoT includes sensors, actuators, and devices. The Sensors in IoT determines the physical quality of objects and compute it into a value which is further read by another user or device. This means that the sensors aid in the collection of real time or very minute data from the surrounding environment. The actuators are used to switch off/on another device or equipment by force when need arises. thus triggering various devices into operation based on the data dynamics. On the other hand the IoT devices, or any other things in the IoT, are non-standard computing devices categorised as consumer, enterprise, and industrial devices that connect wirelessly to a network and have the ability to transmit data.

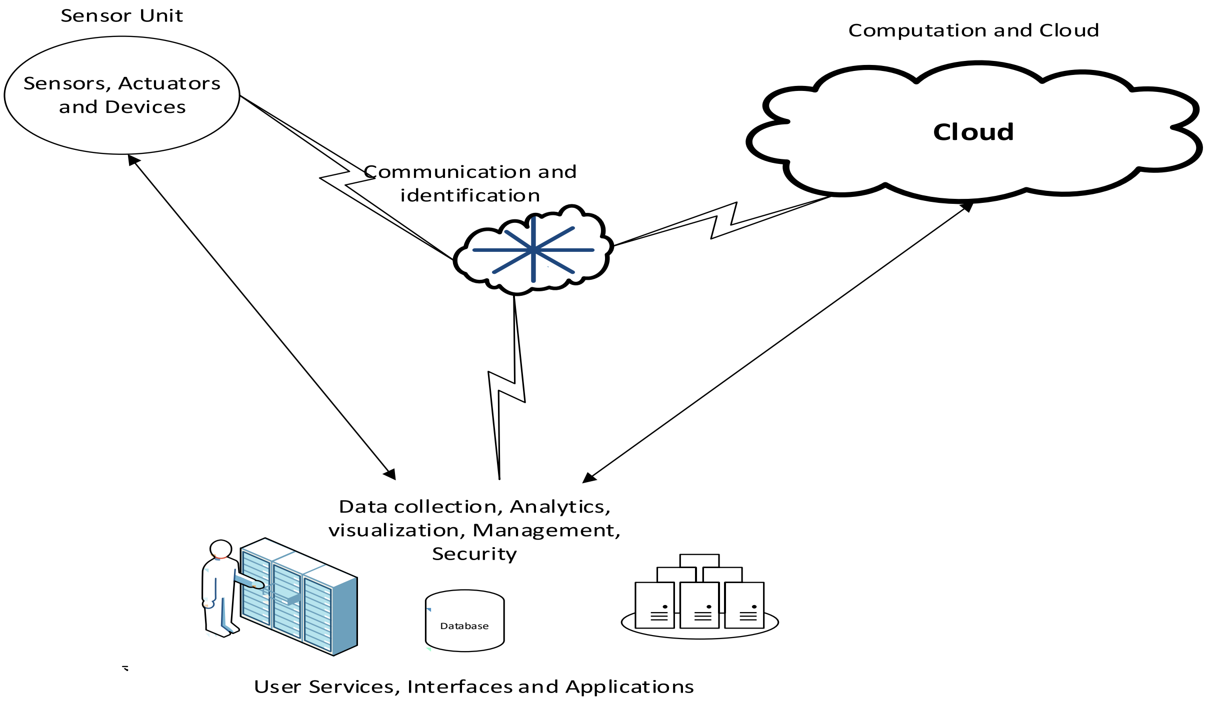

Figure 3: Structure of Internet-of-Things (IoT)

The communication and identification component contains IoT communication protocols such as MQTT, CoAP, AMQP, and DDS are used to connect various IoT objects to send data to management system, and provides authentication and performance gains in networks and operations of sensors, actuators and devices. It assists in the detection of returned faults of the processes, by ensuring that each object acquires a unique identifier. The technologies and protocols used to connect sensors and devices to the internet include Wi-Fi, ZigBee, Bluetooth, LoRaWAN, near field communication (NFC), LTE, cellular, and z-wave

The data processing and cloud component performs all the computations or data manipulations. This includes the collection, storage, and processing of data. All IoT platforms are essentially cloud based, and hence collect, store and process data in the cloud. They support all communication technologies, and transport protocols. On the other hand the services and application component performs the actual data collection, analytics, transmission, visualizing, management, and security.

A. Applications of IoT

Although IoT is still at an early stage, it is considered to be a rapidly growing innovative technology with various applications, functions and services in everyday life and in a wide range of markets and industries, facilitating and enhancing, thus, the role of Information and Communication Technology (ICT) as an innovation enabler in industrial domains [15].

In smart

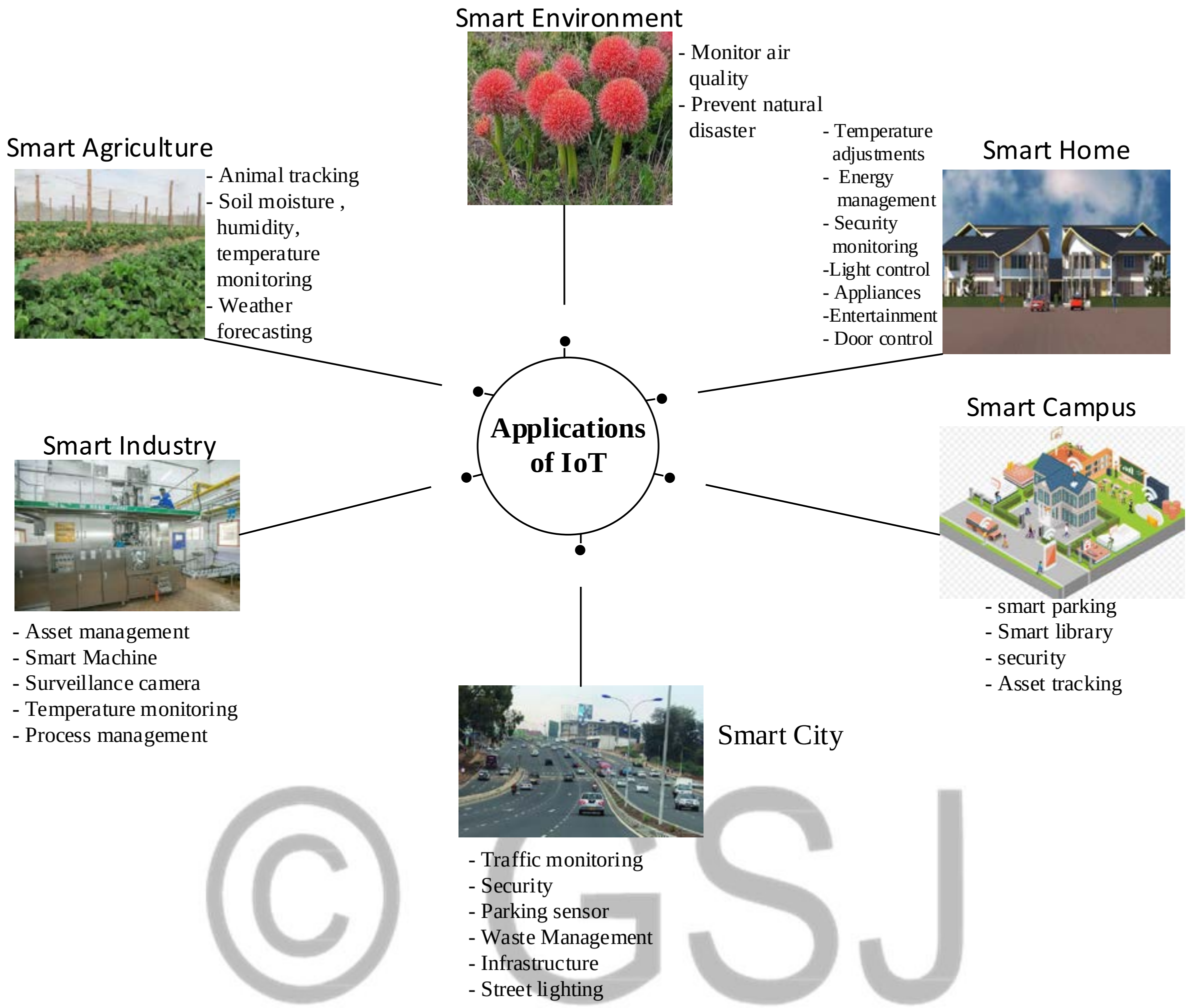

Figure 4: Applications of IoT

The application of IoT spans in almost all domains ranging from education, transportation, agriculture, manufacturing, buildings, health, homes, waste management, resource management, wearable appliances, vehicles, and farming. Many of these areas and more others are undergoing revolutionary growth, putting further demand for battery power requirements which makes LIBS the most prominent of all the batteries due to its unique characteristics. However still it can be seen that even without IoTs there is demand for lots of LIBs and all other battery requirements in general.

In smart homes, IoT plays a vital role which includes security monitoring, appliances management, door control, entertainment, adjusting temperature, and even overall energy management. This is brought about by the growth of the Internet's and Wi-Fi's roles in home computerisation has mainly come about because of the networked nature of different installed electronic devices, such as mobile devices, LCDs, and TVs, washing machines, appliances, that are an ongoing part of the home Internet Protocol network [19]. With the extensive use of smart phones, tablets, and iPads, it means that more people are getting exclusive direct access to their homes from any location as much as they have access to a network. However, this technology does not come without challenges as an Internet Service provider (ISP) or other network observers can gather private and sensitive information about home activities by analysing internet traffic from smart homes containing IoT devices even if the devices use secure encryption [20][21]. This is seen as one of the hindrance that will still put some people away from freely from making their homes IoT enabled.

Campuses are also transforming into the usage of IoT devices extensively to run their operations, making learning to be on the go. Students can get contact with the classroom or lecture halls from whenever they are without necessarily visiting a class of brick and mortar. This means that through smart campus, it is possible that a campus is connected via online by the outside entity, so that the teaching approach based on technology can be conducted in real time [13][12]. In smart campuses issues like smart parking, library, security, asset tracking have all been enhanced by IoT. Searching for parking space is made easy, searching for books in a library, or even some other vital information is enhanced by this revolution. Institutions have been aided to monitor and control every activity in the campus, through the adoption of advanced information and communication technologies (ICTs), thus improving their effectiveness and efficiency of doing things. This study concurs with [22], that within a digital campus, technology can reduce operational costs, improve security, and offer tools for researchers, academics, students and staff.

The IoT devices, the growing analytics and big data capabilities have the potential for enhancing industry and services operations in multiple sectors. Undoubtedly the ubiquitous presence of IoT devices combined with their sensing and communicating capabilities is enabling the opportunity to lower maintenance and operational costs in an unprecedented scale [23][15]. With this technology in place surveillance will be conducted, smart machines will be operated, temperature will be promptly monitored, and other operations within the industry with lower operational costs and maintenance. IoT in industries will therefore encompass the utilization of sensor and information networks to improve business productivity and to generate new business[24], by enabling technologies to perform supervisory control and data acquisition[25].

Cities have not been left outside in the applications of IoT, as it is the technology that is leveraging security, waste management, monitoring air quality, preventing disasters, street lighting, traffic monitoring, road safety [26] and smart parking. IoTs will play an important role in ensuring that there is orderliness in cities, and operations are run with minimal costs. For example in [13] a parking system that provides information related to the available parking lot, and also provides information when the parking lot is full: sensor is put in the parking lot to scan the vehicle that enters the parking lot; the total amount of the vehicles that in the parking lot are revealed on the board; and the information will be processed by the system that provides information to the users about the available parking lot. This will ease congestion in the parking area looking for space, utilize space and safes time. Each application should be fitted with the best suiting battery group for example smart measuring instruments requires Lithium/Thionyl chloride (LTC) batteries, smart data loggers requires PulsesPlus –batteries, smart sensors requires Tadiran Lithium Metal oxide (TLM) batteries, and smart observation devices requires Tadiran Lithium-ion (TLI) batteries.

B. Power requirements of IoT

There are currently a number of power sources for IoT applications [2], which includes: storage, distribution, and harvesting as shown in Table 1.

Table 1: Power sources for internet-of-things (IoTs)

Harvesting	Storage	Distribution
Wind [2][27][28]	Micro-heat engines	Electromagnetic (RF)[29][30][31]
Solar[32][33]	Micro-fuel cells	Wires
Kinetic[29][33]	Supercapacitors[27]	
Mechanical[27]	Batteries[34][35]	
Piezoelectric tiles[36]		

The power availability for IoT devices is a big issue for many IoT applications. For example consider the high control tracker in a smart farm to enable the user track the humidity or temperature in a green house, and since there are no clearly wired connections the device must communicate wirelessly while relying on internal power source. There are several sources of power for IoT devices which are classified as: kinetic, thermal, radiant, and biochemical of which the mechanical and radiant are the most prominent.

The Radio-frequency identification (RFID) is a spectral form of Radio-frequency energy harvesting in which power, as well as information, is obtained from a specific source rather than random ambient RF energy. RF energy can be used to tickle charge or to operate consumer electronics such as wearable medical sensors, headsets, and other small IoT devices. An RFID base station has a scanning antenna which transmits RF signals over a relatively short distance. This communicates with the transponder built into a passive RFID tag [37]and provides the transponder with the energy necessary to wake up, read, and communicate in response. Therefore RFID systems can use radio signal generated by an RFID reader to power themselves and for communication. There are active RFID tags with batteries that operate at a greater distance, but passive tags have a virtually unlimited lifespan. The applications of RF energy includes among others, credit cards, asset tracking, and real time location monitoring systems.

The wind energy harvesting is among the other prominent energy sources that powers IoT devices because it does not pollute the environment and is cheap. More research is being conducted to actualize further the application of wind energy in IoT devices. The windmills and turbines are commonly used to get energy from the fluids, but these kinds windmills and turbines are commonly used to get energy from the fluids, but these kinds of systems cannot be scaled down in a centimetre-sized device, as is necessary for typical IoT systems cannot be scaled down in a centimetre-sized device, as is necessary for typical IoT applications, applications, especially in low-wind speed [27]. However to protect the IoT devices, the wind-induced vibration piezoelectric energy harvesters must be packaged when they are used to power a wireless sensor node in real applications [28].

Despite the fact that some IoT devices may not need to collect data regularly, in many harvesting applications the ambient energy may be insufficient to support the devices with its processing and communication needs. Because of this the rechargeable batteries and supercapacitors becomes handy to be used as storage mediums to suitably collect the energy for harvesting devices output [34]. The supercapacitors are high capacity device with higher capacity, but lower voltage limits than other capacitors. It accepts and delivers charge faster than batteries, but it is prone to excessive self-discharging that leads to wastage of harvested energy. On the other hand the rechargeable batteries is preferred and LIBs is the popular one for powering IoT devices because of its rich benefits. Since some renewable energies have some disadvantages in producing energy such as a solar power cannot produce energy at night, it is recommended that all energy sources can be integrated into a system known as a smart micro-grid. This smart micro-grid also needs battery system as a backup energy that will deliver its stored energy when the main energy producer does not produce energy[35]. However despite all these developments, research is ongoing to deliver cheap, safer, high-density, and more-reliable, and longer lasting LIBs.

The solar cell technology can be used to power IoT devices[28] indefinitely, whereas the solar panels [32] are used to power larger IoT devices as well. However it proves to be less efficient may be at night and if the IoT devices are required to transmit data on a regular basis. The kinetic energy harvesting [29] is another technology used to obtain IoT energy from everyday activities, and thus can be the best option to power IoT devices. The kinetic (motion) energy can be harvested by a wireless node within an IoT form factor and on developing energy allocation algorithms for such nodes. Current research is focused on various methods for estimating harvested energy from acceleration traces [33][38]. The energy availability associated with specific human activities like relaxing, walking, cycling, running will provide some form of energy to IoT devices which has for long not been in focused on. This technology is based on the technology known as reverse electro-wetting. Decreasing size and power requirements of carrying electronics devices make it possible to replace portable batteries with systems that capture energy from human locomotion [39]. But since we have high and very low levels of kinetic energy, both can be used to power smart IoT devices depending on the energy needs.

C. Battery power consumption in IoT

Whether an IoT device is powered by internal or external battery, or an electronic system's external supply, a measurement solution for determining the IoT device's power consumption must support a power-supply range from millivolts to several volts or more. Harvesting energy from all other available sources could permanently supply the node with the required power, thus providing the most promising solution to the power supply problem [38].With the growing number of IoT devices, the power consumption has been an item of concern and a key research problem. It necessitates that the use of artificial intelligence (AI) technologies to detect the abnormal behaviours and react to it instantly. The maximum power management of the IoT devices is one of the major design issue of any IoT devices. To determine the power consumption of many IoT devices requires capability to measure power use across its different voltages. There are a number of software and hardware that are used that measure the IoT device power consumption under any different operating conditions. For example a radio communication tester (RTC) makes it possible to measure and analyse the power consumption of an IoT device while operating under different network connected conditions. Any of these measurement solution for characterizing IoT device power consumption needs therefore to be able to measure a wide dynamic range of current levels, which may run from Nano-amps to several amps. The battery provided stable energy supply, but if causes a replacement cost due to a limited capacity and lifetime of the battery [40]. Since the IoT devices can be operating under various modes like active/working, idle or dormant, and sleep/inactive mode [41], it is realized that low current levels of some IoT designs in sleep mode may be simply beyond the measurement limit of most instruments, especially when high measurement accuracy is needed at those low current levels. The sensor nodes consume more power in active mode than in sleeping mode, thus state-of the-art microcontrollers can stay in sleep power-saving mode with sub micro-amp sleep current [42].

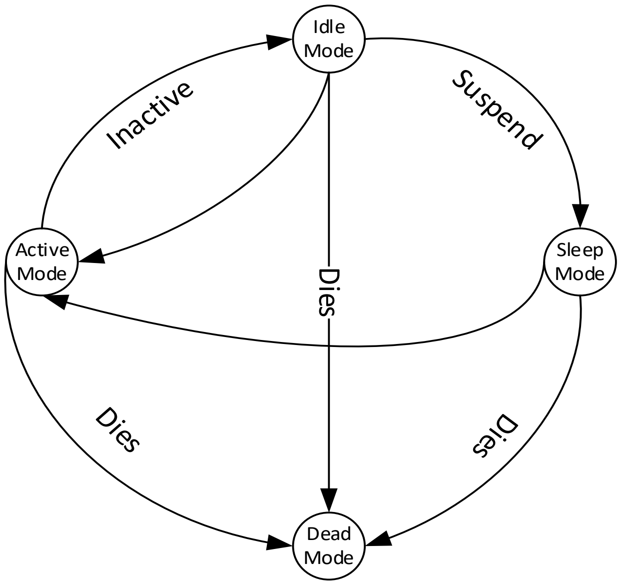

Figure 5: Operation modes of IoT devices

The IoT devices as shown in Figure 2, operates under four modes: active, idle, sleep, and dead mode. However the latter mode is very dangerous and hence IoT devices requires regular maintenance, and on the event one device or component is un-operational it requires to be changed immediately, otherwise it becomes very risky. During the active mode the device is fully functional or working and consumes power depending on the tasks performed. In the idle stage the device consumes less power since there exists no running activities, thus minimum energy usage. In the sleep state all processes are suspended or the components are switched off, hence no power usage. Finally in the dead state, there are no tasks executed, maybe due to battery power failure or device malfunction. The energy consumed in low power mode is influenced by sleep duration [40], and consequently the energy consumed in high power mode is influenced by the active duration of the IoT devices. The IoT devices should be configured in a way that they use low-power mode to reduce the device's energy consumption during idle time. Consequently IoT devices energy consumption is reduced to alleviate the problems caused by independent power supplies. To mitigate the problem of independent power sources, it is necessary to minimize the energy consumption of IoT devices. Reducing energy consumption in battery-based IoT devices can increase battery lifetime and reduce replacement costs [40], as well as reduced power failure and energy losses. Pressure in energy consumption can be addressed at primarily three levels: hardware and infrastructures in general; systems software; and data management. At the hardware and infrastructures it is useful to distinguish between work to produce energy-efficient chips or devices and work at a level that considers infrastructures built with multiple such chips or devices [43]. Also the systems softwares has to be managed mostly resource management, to ensure that resources are made in a way that they are light weight so as to consume less energy. Data management involves the design and deployment of policies, architectures, and procedures allowing the accurate

management of the full data lifecycle. As shown in Figure 3, the projected market share of LIBs used in handsets from 2012-2020 in million (US$), is likely to keep soaring high. If other devices that use batteries are considered based on these statistics, it means that LIBs are under pressure as the technology is improving.

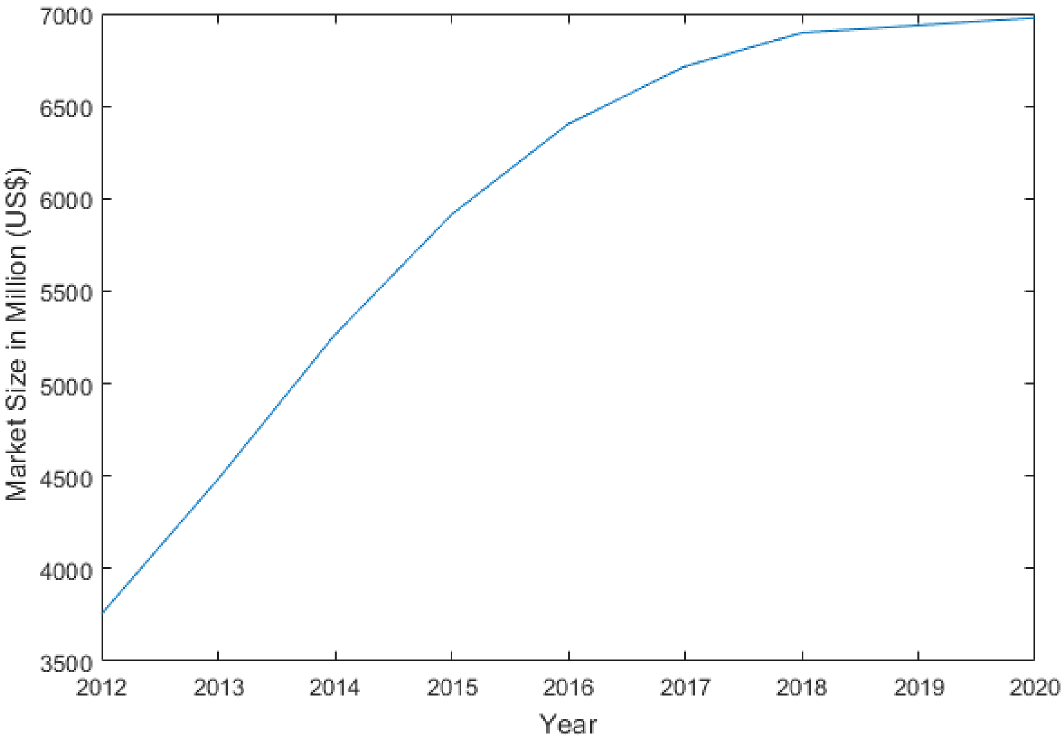

Figure 6: Projected market for LIBs used in handsets from 2012-2020 in millions (US $)

D. IoT battery option

The battery is the main power option for IoTs and LIBs are playing a key role in the IoT industry. The main challenge of deploying IoT battery-powered sensing systems is managing the maintenance of batteries [34]. Due to this reason, practitioners often employ prediction techniques to approximate the battery lifetime of the deployed devices [34]. If L_h is the battery lifetime, C is the battery nominal capacity, and Q_h is the IoT device charge consumption per unit hour, then the battery lifetime can be evaluated as:

$$L_h = \frac{C}{Q_h} \qquad (3$$

IoT depends on independent power sources, and as such if a failure occurs in the power source the running task fails automatically. This call for restarting the task again when the power resumes thus leading to energy wastage during task restart and failure. This problem can be moderated by minimizing the power consumption of IoT devices[40]. Further according to literature [44], offloading the data between IoT edge devices and smart devices like phones/devices/gateways for completing a task in an efficient energy and communication way will aid in utilizing the energy used by the devices thus improving the battery life. Also it is crucial for IoT software to leverage the low power modes of the hardware and put the device to a sleep mode for as long as possible [45] to conserve energy. Further integration of renewable energy into interconnected energy systems [46]is another key energy option which will yield to not only cutting on costs but also to clean the environment. Therefore the IoT devices should be designed to achieve long term maintenance free monitoring and use of IoT nodes that use energy preserving and efficient Radio frequency (RF) technology.

IV. Expectations

There is increasingly common battery-powered devices in use and in the market today. Some of these devices comes with common and some variant expectations some of which may be domain or industry specific as to where these devices are used. The main expectations that these battery-powered devices comes with that are a consideration to the manufacturers production list includes:

- ✓ Increasing mobility
- ✓ Higher data demands
- ✓ Larger, color, touch-based displays
- ✓ "Always-connected" applications
- ✓ Complex interaction: SW apps, FW, HW
- ✓ Competitive advantage – huge business impact, especially in medical and Industrial IoT
- ✓ Life safety, medical applications growing
- ✓ Invasive, expensive battery changes
- ✓ Disruption: patient & health care professional

To ensure that the IoT battery-powered devices meet their expectations effort has to be put in place to ensure that these devices achieves : high bandwidth to capture fast turn-ons; seamless ranging for highly dynamic signals; RF detection; fast setup and data collection

V. Opportunities

Battery prognostics is still considered relatively immature as compared to diagnostics, thus more focus is on developing prognostic methods rather than evaluating and comparing their performances [4]. Consequently, there is a need for dedicated attention towards developing standard methods to evaluate prognostic performance from a viewpoint of how post-prognostic reasoning will be integrated into the health management decision making process [47]. There are many opportunities for prognostics and health management of LIBs, but they have been met with various challenges in equal measure. In this study these opportunities and challenges from LIBs perspective are analysed from four perspectives namely: technological, financial/cost, security, and environmental. Table 2 provides a summary of these opportunities and challenges of LIBs.

Table 2: Summary of opportunities and challenges of LIBs

Aspect	Opportunities	Challenges	References
Technological	- Existence of recycling technologies - Growth in demand for LIB	• Performance of higher power, larger energy capacity • RUL Prediction, SOH diagnosis, Aging • Enduring adverse circumstances • Development of low weight battery • Reliability • Degradation uncertainties	[47-54]
Financial/Cost	- Intelligent cost management - Cost savings	• Lower cost • Battery degradation costs	[55-58]

Security	- Battery state monitoring system	• More safety assurance	[59-63]
Environmental	- 3R -principle: Recycle, reuse, reduce - Mitigated emissions - Integration of renewable energies	• Disposing waste batteries , • How to reduce production of new batteries	[7][48] [49] [50]

The LIB technology is considered as one of the most promising for the near future by a majority of literary sources [51]. However a lot has to be done to ensure that batteries of higher power performance, larger energy capacity are realized, as well as improving the batteries to endure adverse circumstances. Consequently the prediction of RUL, monitoring of battery aging, and SOH diagnosis requires technologies that are accurate in order to avoid catastrophic failures. This is explained by the way it has caught the market share in commercialization in consumer electronics such as cell phones, laptops, video cameras, digital cameras, power tools, and other portable electronic devices [52]. LIBs have many advantages which include [53][54][55][52][56][57] light weight, high energy density, low self-density, no maintenance, faster recharge, and customization. However this technology faces some challenges like reliability, degradation uncertainties, enduring adverse environment and remaining useful life prediction.

In the recent past LIB costs have been reduced significantly by almost 65% from 2010 [58]. Several countries are working around the clock to see how best they can substitute fossil based powered energies for technological option of greener/renewable energy to further cut on the cost as well as to conserve the environment [4]. Manufacturers are working on how to employ intelligent cost management methods in-order to produce low cost LIB. This is partly achieved by recycling of used LIBs, which could have gone into a waste dumped in a landfill. However the development LIBs and its certification of safety critical applications are very expensive.

These costs can be reduced by encapsulating safety-critical components, and safety measures can be restricted to the respective parts [59]. Accounting for the battery aging is crucial as the cost of LIBs has a crucial significant impact on overall system cost. The modelled battery degradation cost includes the impacts of the battery temperature, the average SOC, and the DOD on fading the LIB capacity [60]. But the general costs of batteries reduced tremendously from 1000$/kWh in 2008, to 268$/kWh in 2015, which is a 73% reduction in 7 years [61]. If this trend continues, in the future it looks promising to consumers of IoTs, but if alternative measures to sources of energies are not sought, then the meagre resources for the manufacture of LIBs will be depleted.

The safety of LIBs is paramount to ensure confidence and widespread adoption of IoTs in our society, as they are a proven technology for powering electronic and automotive applications and their continuous use in the future is undeniable. For enhanced security and more accurate SOC estimation, the parameter values of equivalent circuit model (ECMs) should be continually updated since surface temperature measurements alone might not be sufficient to ensure safe battery operation [62]. During cycling, cells within a pack exhibit non-uniform properties which may lead to some unbalances (e.g. voltage variations between cells) that may trigger a safety hazard [63]. When IoT devices are used outdoors changes in temperature and load can cause performance degradation in LIBs. Battery degradation may lead to leakage, insulation damage, and partial short-circuit. If there is no online detection of degradation, further battery usage will cause serious situations such as spontaneous combustion and explosions, especially if the current state of health has not been assessed in a timely fashion, or the future battery health state has not been estimated [64]. The main thermal safety issues of LIBs to be addressed are overheating, combustion, and explosion and cycle life. To avoid any catastrophic incidences caused by degradation of LIBs and to predictively maintain the safety of IoT devices, carrying out research on RUL prognostics of LIBSs is of great importance [65][64][63][66].

The use of LIB will be the next big thing as many governments are fighting against production and sale of vehicles powered only by fossil fuels in favour of cleaner vehicles. This is in a bid to clean up the country's air, or in fighting against global warming. There are several opportunities in relation to environmental aspects in the use production and sale of green energy to the fight global warming. Several environmental opportunities that exist include but are not limited to: *3R-principle: recycle, reuse, reduce; mitigated emissions; integration of renewable energies.*

Consequently the LIB consumers requires awareness on taking part on the 3R-principle, since many consumers prefer new batteries, making spent batteries to have little potential for reuse ending up being dumped along with other urban solid waste. Taking into account the importance of key parameters for the environmental performance of LIBs, research efforts should not only focus on energy density but also on maximizing cycle life and charge/discharge efficiency [67]. The application of the 3R-principle to LIBs will bring savings quantified in terms of energy and cumulative energy extracted from the natural environment [68]. It will be seen how material or cell recovery from existing cells will be another source of future materials for LIBs [69]. Therefore the 3R rule for reuse, recycle, and reduce should be employed purposely to reduce the extinction of the rare iron ores, and this will go along line in the conservation of the environment. Current research is coiled towards these principles to improve on the technologies around it.

VI. Challenges and open research issues of IoT

The management and maintenance of batteries is one of the key challenges of deploying IoT battery-powered sensing systems. Due to this challenge commonly the practitioners often employ prediction techniques to approximate the battery lifetime of the deployed devices [34]. Reka and Dragicevic [70] outlines three major challenges namely data leakage, cyber-attacks, and unpredictable or unreliable internet connectivity, of which Lopez et al. [71]agrees that raising user awareness and promoting privacy sensitive behaviours is a major open research concern. According to them when data is in wrong hands then calamity can arise due to its inappropriate usage, and at the same time if there is an internet downtime then the systems will not be working and this can lead to total system shutdown. Another challenge is transferring huge volumes of data efficiently[72] as the number of IoT devices is growing exponentially. This challenge however can be solved by designing of a mobility management model that can help in triggering efficient handover and selecting optimal networks based on multi-criteria decision modelling. Consequently a reliable system architecture which integrates green IoT with 5G network can speed the process as it requires to communicate with other heterogeneous networks efficiently with minimum energy requirements.

Due to the existence of a myriad of challenges, according to the literature [15][73], the following open research issues of IoT exist: data confidentiality, security and privacy; scalability and interoperability; data, operation, resource and energy management; functionality safety and fault tolerance; availability, reliability, mobility and other QoS criteria; standardization activities, architecture and protocols; identification and networking addressing. These open research issues for batteries and IoTs can be summarized as:

Design trade-offs:

Managing the maintenance of batteries is one of the greatest challenge of deploying the IoT battery-powered sensing systems [34]. It is envisioned that to offer best result the IoT devices deployable should be low-power ones, which is still a challenge too. However this challenge can be addressed by measuring the sleep current and the active current separately, using two different shunt resistors: a large shunt resistor for measuring the sleep current with high accuracy, and a small shunt resistor for measuring the active current without resetting the board. At present the major limitation of measuring current is that the major device under use needs to be attached to the battery. Another challenge and research issue is that still IoT networks are limited in scope, with majorly less than 10 nodes in a network that can vary widely in power consumption depending on the application [2]. During design of batteries the following should be considered: battery type & capacity , processing power , component size & quality , cost , Firmware behaviour in the MCU , functionality, features, performance , connectivity, and user experience.

Long-life and reliability:

One of the biggest challenges in battery reliability is the detection of trace contamination in assembled cells. Often, contamination issues are not highlighted until after failures have been observed. Any cell or battery that has an open recall for issues regarding contamination should be considered defective for safety reasons [8]. When contamination particles result in internal short circuits, rapid self-discharge of the cell or battery is observed which further can cause harm to the IoT devices of lower their efficiency. Long life and reliability is a must to meet the total cost of ownership expectations of most IoT applications minimizing replacement and sensor servicing needs while increasing reliability and user confidence for industrial, commercial and residential applications. The IoT architecture contains three layers where, lower layers are responsible for event related aggregation, middle layers are responsible for storing and retrieving information produced by higher level and lower level layers, while the higher level layer is responsible for query related data. The major challenge is energy efficiency and reliability in lower level layers because devices and communication channels used in lower layers are lower power edge devices like sensors devices and lower power radio links. In the higher layer the challenge is data management and processing because they handle a huge chunk of data, while in middle layer the challenge is controlling the temperature dissipated for storage devices [74]. LIBs should offer longevity, quality, and autonomous operation required of any type of sensor application. This poses a grey are for research in batteries and IoT in relation to extending device lifetime [74] by balanced energy utilization and reliable data transfer are major concern in IoT technology.

New and disruptive battery technologies:

The LIBs technology is facing competition from new disruptive battery technologies that may make it to pave way for high-performance batteries, unless more is done to keep improving it. These technologies include silicon-based batteries, paper-polymer battery, magnesium battery, potassium-ion battery, room-temperature sodium sulfur battery, proton battery, Nickel-Zinc battery, aluminium-ion battery, graphite-ion battery, and many more technologies. These technologies places LIBs at the edge of research and development to maintain a competitive niche in the market and make it a sole market player.

Privacy and security:

Security and privacy is a major concern despite the numerous benefits that IoT comes with. This ranges from the security of the IoT devices, and data privacy of the information stored, transmitted, shared or information application [73][25]. This calls for suitable remedial measures which can be done with the advancement of technology by bringing in new authentication schemes, encryption methods, public key infrastructure (PKI) and also by creating standardized application program interfaces [70].

VII. Conclusion

Lithium-ion batteries as an energy source were evaluated for use in IoT devices. IoT power requirement, power consumption, and battery options were evaluated and compared. Some of the factors that makes Li-ion fit for IoT devices includes battery lifetime, high density, limited memory effect, low maintenance and rechargeable. This makes them suitable for space constrained products, weight constrained products, cell phones, IoT devices, and electronic watches. To increase power saving performance and decreasing consumption can be achieved by thinking over the design of both the software and hardware. However, the life of an IoT device is not only dependent on the battery type and capacity, but also the techniques and the design put in place when building out, and IoT device and application.

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