# Power management factors and techniques for IoT design devices

**Conference Paper** · March 2018

DOI: 10.1109/ISQED.2018.8357314



Pradeep Chawda
Texas Instruments Inc.

# Power Management Factors and Techniques for IoT Design Devices

Pradeep Chawda[1], Anupriya Prasad[2]
[1]Texas Instruments, 3833 Kifer Rd, Santa Clara, CA 95051, USA
[2]Texas Instruments, No. 66/3,Bagmane Tech Park, C V Raman Nagar, Bengaluru (560093), India
[1]E-mail: pkc@ti.com, [2]E-mail: aprasad@ti.com

## Abstract

Internet of Things (IoT) is a system that renders the ability to exchange information and actions in an amalgamated environment consisting of machines and humans over a network. Such extraction of information flow through network will optimize the limitations of the physical world. A key player in the realization of IoT system is power management. In this paper, the need for power management in an application based IoT design is motivated. The paper outlines the factors concerning power management in IoT design for example, aging in battery sources, sleep and shutdown mode of operation, etc. Furthermore, the paper reviews some of the techniques like power grating, maximum power point tracking, etc. for currently used power sources that aid to enhance the performance of the system. The technical challenges faced in the IoT field for circuit power up and battery lives have also been discussed. Since power is imperative in variegated engineering disciplines all around the field of science and also is a fundamental prerequisite for the IoT system design. Wireless sensors, servers, Ethernet, and smart appliances, as a part of an IoT based solution are all affected by the scope of power management. With the novel IoT solutions operating under the absence of human intervention at data collection stage, it is crucial for the devices to be powered up smartly to offer accurate results and good performance.

## Keywords

Internet of Things (IoT), Integrated Circuit (IC), System on Chip (SoC), Predictive Power Management (PPM), internet of battery-less things (IoBT), Wireless Sensor Networks (WSNs), Low-dropout regulators (LDOs), maximum power point tracking (MPPT), Power Management Unit (PMU)

## 1. Introduction

With IoT covering innumerable sectors of market based operations, it remains a challenge to maintain the durability of the systems developed and decrease the amount of energy invested in reconfiguring or maintenance of the system. To reduce the energy wastage and make our designs much more efficient, power management techniques are used in IoT devices. Thus, power management is a key challenge in the field of IoT devices using batteries for a longer time since various factors impact the battery lifetime and understanding their role helps in optimizing our solutions.

According to Incorporated Research Institute of Seismology (IRIS), earthquakes of magnitude 8 or greater occur about once a year. This kind of application is implemented in IoT using vibration sensors (accelerometers) and PIC (Peripheral Interface Controllers), communicated through a ZIGBEE protocol. For such an application, the IoT system should be able to produce a successful warning when an earthquake of a higher magnitude is felt. The sensors used should operate in active mode throughout the year and give accurate reading/warning when an earthquake of magnitude 8 or above is about to impact the area. The sensor circuit battery or autonomous power source needs to be fully functional for an accurate measurement and delivery of the final goal in the example above. Here the performance and reliability of the energy source plays a crucial role. The users cannot afford the consequences if the battery life dies when an earthquake of magnitude 8 strikes the area after one year of installation of such an IoT system. Similarly, many IoT applications need to run for years with batteries in an alienated environment and reduce the overall energy consumption to improve performance. Hence, a low power solution with high efficiency and longer lifetime is required.

In this paper, survey of the power management solutions in realizing IoT applications are covered. Several surveys on IoT power management have been published such as [1]-[31]. The aforementioned surveys have showcased the capability of designing IoT solutions with the effect of key factors impacting the power management. However, these surveys are yet to capture the more recent trend and the challenges faced by battery life in IoT based systems. The aim of this paper is to provide a lucid picture and consolidated understanding of the on-going research in power management for IoT design area and challenges faced.

## 2. Literature Review

A lot of research and development focus is laid on the field of IoT and various surveys have been carried out for Power Management in IoT system devices. The techniques covered in these surveys vary considerably, and with new technological advancements come new challenges and prospects. In this section, a succinct overview the past papers in the field of power management specific to IoT design case and the advantages and disadvantages concerning each technique have been presented.

In a research paper on integrated PM in IoT devices under wide dynamic ranges of operation and dynamic behavior of source and loads, static power delivery network (PDN) will not be able to suffice efficiency requirements. Therefore research has been carried on dynamic PDN components with adaptive design capability, control for interface circuits and energy harvesters. Moreover, advancements in this technology have been suggested that will co-optimize PDN components and make the system robust. [20]

The approach of predictive power management (PPM) for IoT battery-less things is focused on a combining deviation based prediction energy weight allocation, optimal working point, and efficacious energy transmission power adaptive control that guarantees basic power loss of IoBT systems by predicting the power consumed based on weights assigned using different parameters. [12]

BSC-MAC is an approach that actuates the source nodes, nodes on the network as root and maintains a sleep schedule conferring to these nodes. The advantages of this technique are the high efficiency and ability to produce better results with increasing number of nodes. Other advantages include reduced energy consumption and increased throughput. [13]

Another technique is based on power reduction in wireless networks using versatile fuzzy-MAC. In this paper, Fuzzy Logic that adapts MAC parameters is used to optimize lifetime of sensor devices. The advantage of this technique is that this approach led to increase in expiring node's lifetime and also improved the lifetime of node near sink. The limitation is the time taken in calculation of MAC parameters. [14]

Focus has also been laid on the approaches for power advancement in Bluetooth using MAC scheduling: A TDD wireless system driven by master is used in the approach. These strategies use a low current power mode in Bluetooth to force restructuring at MAC layer. The pros of this technique are the power enhancements over conservative scheduling and energy consumption reduction from nominal delays in the system. [17]

Existing literature has also mentioned a new technique using a neuro-fuzzy algorithm for energy improvement in smart home. This capability developed energy efficient system in smart home application which uses fuzzy system. This offers an advantage in smart home sector of IoT based devices. The disadvantage offered is that eradication of noise occurring in input patterns due to straying has not been considered. [15]

Approach presented in the paper "the technique for self-powered Bluetooth network for traffic light convergence management" focuses on a procedure to control the sensor nexus in correspondence to piezo electrics which measure the vibration delivered by the entry of vehicles on the street distinguished by Bluetooth sensor hubs. [16]

Research has been done on fuzzy ensample for energy efficiency in smart home. The fuzzy logic based device discovers the sleep time of gadgets in a computerized home environment in light of BLE. The advantages of this power management technique helped in improving device lifetime by 30% and the sleep time of devices that were inactive. The future scope of this approach deals with the use of Gaussian functions to improve performance and accuracy of the system. [3]

## 3. Limitations in existing work

Some of the challenges in the current methodologies are as follows:

1) An integration of PM in separate devices aiming for a complete IoT solution is still to be developed upon. A power management unit integrates the PM techniques in every block or device finally adding to the end design block. Thus an integrated approach addressing designing power management unit (PMU) and concerns for various factors has the scope of development.
2) Wireless power transfer is a complex process and has been not concretely witnessed in different power management techniques. Their design is concrete in the upcoming IoT supported solutions and managing power in such cases needs to be addressed.

## 4. IoT Design blocks

Fig.1 demonstrates the IoT design architecture building blocks diagram and power assets to support each block.

1) **Nodes:** This block alludes to the collection of information which is further shared over the network and processed by an IoT system. This can be carried out using sensors, which require power in the form of heat, vibration, battery or wireless power transfer.

2) **Gateway/Bridge/Router:** This block is mainly the transmission stage in which the information is shared over the network with the help of servers, to be processed further.

3) **Cloud:** The cloud computing is a part of service platform and enabler that involves handling, breaking down data streams and forwarding the data further for IoT applications.

In Power management of IoT solutions, designers deal with all the three building blocks of the system. This paper is primarily concerned with the power system of the sensing node and other power units associated with microprocessor and integrated chips (ICs).

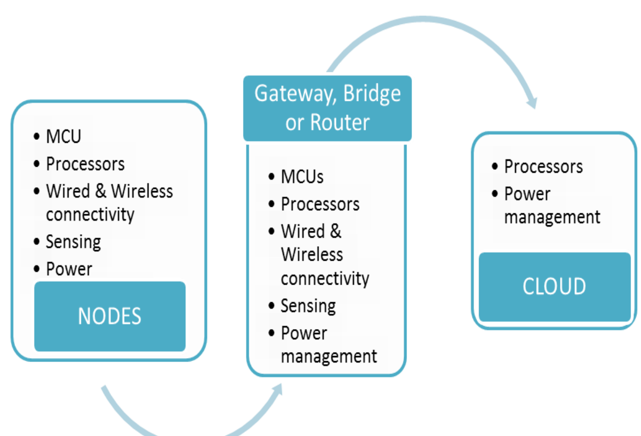


**Figure 1:** Building Blocks of IoT design system

## 5. Power management

Power management is a notable concern for IoT devices considering application based sensor use; it is required to be powered by small batteries for extended periods of time. The semiconductors used in such devices must be designed for low power.

The Wireless Sensor Networks (WSNs) fundamentally utilize nodes integrated in application specific domain with the ability to recognize and capture vital information. Usually, the sensing nodes operate by fetching energy from a battery source. Using Figure 2, typical power management architecture of an IoT is explained. The rectified input is shared with the switching regulator, which further uses Battery management block, for example, the sensors output is transmitted to switching converter and further the output of DC-DC converter is sent to battery management unit that focuses on power management of the IoT system. Various blocks in the architecture are used in very familiar IoT systems and some of the aspects of blocks concerning battery, LDOs, DC-DC converters need to be addressed for power management of whole system.

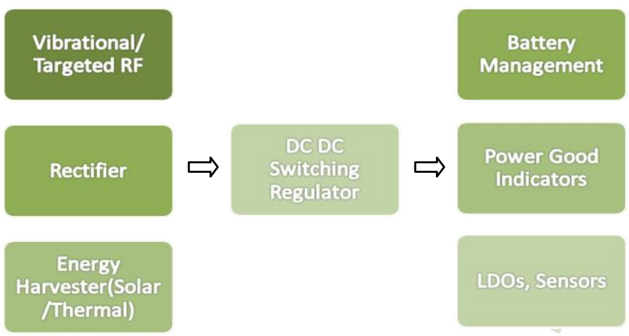


**Figure 2:** Typical power management architecture of an IoT node.

### 5.1. Power limitations in Battery/Power Sources

1) Currently used sensing devices include Wi-Fi-based sensors running on 2xAA batteries. Earlier solutions used non-rechargeable batteries to strike out balance between cost, convenience of use and availability. This will render the requirement for replacement and will showcase a major issue in the future of IoT devices.
2) In rechargeable energy source applications, NiMH batteries are replaced by NiCd batteries for better efficiency. However, the discharge rate is high for NiMH batteries that allow an approximate of 500 charge-discharge cycles for each cell which makes their use unfeasible for longer time in IoT system use.
3) Additionally, energy harvesting sources using mechanical, thermoelectric, solar, etc. sources fail to generate 50mW of power in transmission mode required by low power devices and consume even lower in sleep modes. Therefore, it is difficult to be considered for energy storage and smooth operation of IoT sensing system. In certain applications, fully self-powered systems may remain impractical, but opportunistic energy harvesting where the secondary battery is supplemented with energy harvesting will become feasible. These will be of significant application in distributed sensor nodes where many of these devices may be deployed and may remain physically inaccessible. This is when internet of battery-less things (IoBT) comes into play.
4) Wirelessly powering up devices is another method into play. Electricity can be directed via magnetic inductive coupling or electromagnetic radiation. Designing such systems is complex and security compliance is another perspective to be considered because electromagnetic fields are harmful to living things.
5) Power management blocks are analog and mixed signal circuits. In this paper, power related features of these blocks are addressed and one such block is low-dropout regulators (LDOs). Analog linear regulators are supplemented with synthesizable, process and voltage scalability; digital linear regulators have been enabled for fast response at extremely low controller currents. They are frequently used where supply of different voltage is required on System on Chip (SoC) and isolating external noise source from internal SoC.
6) In solutions like super capacitors, along with the benefit of unlimited charge-discharge cycles (>100,000), is the disadvantage of high self-discharge (up to 25%/day). Some solutions like solid-state thin-film offer low power density but high energy density.
7) DC-DC Converters/controllers are used when there is relatively high voltage drop than LDOs. Different configurations of buck, boost converters and controllers can be used depending on the specification of output voltage required and the type of compensation required.

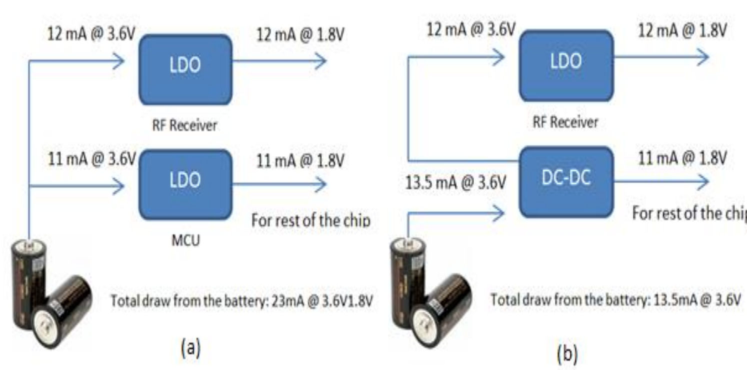


**Figure 3:** (a) MCU without a buck converter, (b) MCU with an integrated DC-DC buck converter.

Figure 3(b) shows MCU integrated DC-DC buck converter draws less power from the battery as compared to figure 3(a) where LDO inside MCU draws more power from the battery. Thus, DC-DC converters can achieve 40 percent lower active mode Power compared to MCU without DC-DC buck converter.

Besides apropos power storage technology, it is required to consider power management as it allows certain parts to operate in low-power mode when parts are not required and also enables battery recharge simultaneously. Low-power state operation also depends on impedance matching in the power source, transducer and the electrical system. Other impacting features are voltage regulation in the circuit, internal compensation, maximum power point tracking (MPPT), and the form factor.

### 5.2. Associated Problems

1) The use of capacitors at the output for LDO in the system can add to the cost and decrease reliability due to solder joints. Another drawback of using LDOs for the generation of low voltages from an input power supply is that they consume power in relation to the drop of voltage from input to output.
2) The drawback of a DC-DC converter is that it can cause switching noise into its output voltage because it is switched mode circuit. In buck/boost converters, it is noted that there exist large variations in the inductance and the value of the inductance degrade over time. A key challenge is to maintain efficient power management in spite of such variations and dynamic changes related to aging.
3) Battery life is limited in the currently used battery sources in IoT design systems.
4) Test and measurement of device: The test and measurement of actual devices covering different temperature of operation and corner cases is vital. The oscilloscopes sometimes have noise which reflects in circuit output noise for low current and voltage circuits. Thus instruments used and PM techniques are vital for measurements like capturing battery current drain in all operating states to profile total current drain. Different model types of batteries i.e. portable, etc. need different techniques for test and measurement.

## 6. Factors impacting Power Management

The certain criterions required to be fulfilled by designed power management solutions are:

1) **Voltage accuracy:** Tolerance specifications for voltage are strict in loads such as microprocessor, memory, peripherals, etc. and the designed power converter should be able to limit the output voltage within the voltage tolerance limits. The feedback from output voltage is matched with Voltage reference for which limits play a crucial role. This is commonly used in reference for data converters, op amps, and comparators, etc. The characteristic benefits of voltage accuracy are less power consumption, good accuracy and good power supply noise rejection.
2) **Sleep and shutdown:** In a battery based application, the data receiving and transmitting duty cycle decide the battery lifetime. Between the phases of data transmission, it is vital to keep the standby mode currents really low so that there is enough energy in the battery source for its active use. Figure 4, displays the current profile for IoT devices. In sleep mode the current requirement of the devices drops down to Nano Amperes to micro Amperes. Identification of this factor in sleep profile helps to enhance battery life by varying the power transmitted to the devices.

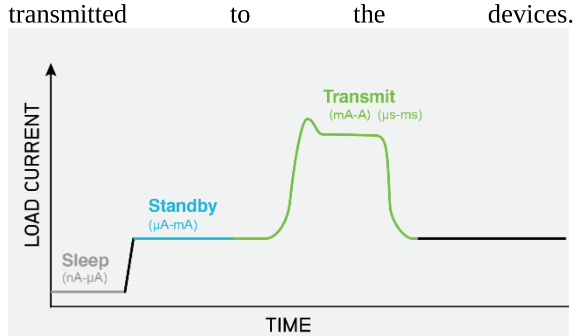


**Figure 4:** Typical current profile for IoT devices

3) **Efficiency:** Thermal management and energy savings are two of the many important facets that are improved with high efficiency of designer energy source.
4) **Built-in low power modes and high light load efficiency:** In some applications, sleep mode when the nodes are inactive comprises of long durations compared to the short durations of high activity. The converters operate in pulse frequency mode by decreasing the frequency to increase the efficiency at low load. High load efficiency is equally vital in improving reliability of the design.
5) **Aging:** Energy is dissipated as heat which increases the ambient temperature including the integrated circuit (IC) temperature. This temperature rise speeds up the aging factor. Although, a semiconductor design for IoT solution operates from 2 years to 10 or 15 years, even a small increase in design ambient temperature could have significant rise in device junction temperature and lead to aging. Even when the devices are inactive, aging occurs due to continuous constant stress across transistors. Attention must be paid on package as well.
6) **Scalability**: This is the capability of solution to be open to a dynamic environment and be responsive to meet the changing needs. Most smart objects have software drivers handling the processor interface with the power management system because the power requirements of a multi-core processor are not

always aligned to the requirements of a single-core processor. To design the power solution, scalability is needed not only in terms of hardware but also software. Thus, planning the use of single software in the family of power management system is beneficial.

7) **Power up timing and sequencing:** Startup voltage of the different rails needs to be tuned depending on the system operating frequency and type of cascaded systems/blocks. Clock speed and cycle both enhance the circuits and reducing the power up time helps in achieving better efficiency and performance. The timing and sequence also need to be adjusted and optimized depending on the use case. For example, portable battery operated systems could have inrush current limitations which will require output voltages to come up at a slower slew rate and spread apart in time. These limitations wouldn't apply to an automotive system where faster the power up encounters better operation. Typically the voltage, timing sequence and slew rates are controlled using external circuitry consisting of resistors and capacitors. These parameters need to be considered while planning for the power management of systems concerned with timing and sequencing.

## 7. Approach/Methodology for Power management

Power Management techniques provide solution and try to address the problems mentioned in the above sections using various techniques. With different applications, the IoT power architecture is optimized, but the problems faced in general with power management of blocks in IoT can be addressed using techniques as follows:

1) **Power Grating Technique** – In this technique, energy is saved during shutdown and sleep/active nodes by introduction of an electronic switch between chip and power supply line. This technique is implemented in devices that have a large sleep time and work in the inactive mode during a substantial amount of time during the device operation. Therefore energy is saved as less power is consumed during the sleep time and in case of non-rechargeable sources, the source lifetime is increased.
2) **Power Matching Technique** – This is based on selection of battery according to capacity of cells. To allow continuous power flow at low currents, the power is managed by transceiver nodes and internal nodes.
3) **SPCPM Technique**- Simultaneous power control and power management (SPCPM) is based on simultaneous active/sleep nodes. The node maximizes the number of transmitted packets along with keeping in concern the time-varying amount of energy. Monitoring a time based pattern helps to optimize the transmitted energy packets and save power.
4) **New Measurement Solutions**: Traditional measurement techniques are complex and time consuming and do not deliver measurement accuracy required to optimize power management. Seamless current ranging and long-term, gap free data logging overcomes the traditional measurement techniques for battery drain current. It is a patented technology in which the seamless current ranging is combined with digitizers for improved digital measurements. Traditional measurement techniques are complex and time consuming and do not deliver measurement accuracy required to optimize power management.
5) **Predictive Energy Allocation Technique**: In this technique, parameters impacting energy are allocated some weights and it is used to provide envision for future energy generation rate and helps to trace the power to evaluate energy utilization rate, system power failure time and system power loss. These metrics help to deduce the life of IoT devices in a system.
6) **Power Capping**: This technique is used to restrict power consumption of a design to a safe level, typically a design time estimate called thermal design power (TDP). This limit is kept because beyond this thermal violations of the system may occur. Dynamic voltage, frequency scaling (DVFS), Power gating (PG), threshold level computing and adaptive scheduling are other factors having power capping benefits in power management.

## 8. Conclusion/Future Scope

In this paper, the factors that impact the power management of IoT systems have been mentioned along with the limitations of currently used batteries and power sources in IoT. While providing the literature review, the associated problems and the approached power management techniques for improving the performance and robustness of an IoT design are outlined. Tools like Source Measure Units, DC power Analyzers and Digital Multimeters help understand power consumption patterns and battery life. Online design tools for designing power solutions can also be put to use.

With the future scope of wireless technology into play, consolidating a system using wires will soon be obsolete, so wireless power transfer is critical. This helps to extend and achieve the most out of the breadth offered by IoT solutions. The IoT applications focus on smart power management techniques to optimize the solutions supporting reduced overheads and enhanced efficiency to attain consistent performance in IoT solutions.

## 9. References

[1] Deepti Goyal and Sonal, “Power Management in Wireless Sensor Network”, Journal, IEEE, New Delhi, India, 16-18 March 2016.

[2] M. Collotta and G. Pau, “Bluetooth for IoT: A fuzzy approach to improve power management in smart home”, Computers and Electrical Engineering, vol. 44, pp. 137-152, 2015.

[3] Daniel Minoli, Kazem Sohraby, and Benedict Occhiogrosso, “IoT considerations, Requirements, and Architectures for Smart Buildings-Energy Optimization and Next-Generation Building Management Systems”, IEEE, IEEE, 4 Jan 2017.

[4] M. Collotta and G. Pau, “A Solution Based on Bluetooth Low Energy for Smart Home Energy Management”, Energies, vol. 8, no. 10, pp. 11916-11938, 2015.

[5] https://www.tek.com/application/internet-of-things-dc-power-consumption.

[6] Lei Wei, Weiwei Miao, Chengling Jiang, Bo Guo, Wei Li, Rui Liu, Jun Zou, ”Power Wireless private network in Energy IoT: Challenges, opportunities and Solutions”, ISC2, IEEE, Wuxi, China, 2 Nov 2017.

[7] M.P.R.S. Kiran, V. Subrahmanyam, and P. Rajalakdhmi,”Novel Power Management Scheme and Effects of Constrained On-node Storage on Performance of MAC Layer for Industrial IoT Networks”, IEEE Trans, IEEE, 26 Oct 2017.

[8] Shiquan Fan, Liuming Zhao, Ran Wei, li Geng, Philip X.-L. Feng, “An Ultra-Low Quiescent Current Power Management ASIC with MPPT for Vibrational Energy Harvesting”, ISAS, IEEE, 28 Sept 2017.

[9] Hayeon Choi, Youngkyoung Koo, Sangsoo Park, “Segment-aware Energy-efficient Management of Heterogeneous Memory System for Ultra-Low-Power IoT devices”, Computer and Energy Science (SpliTech), IEEE, 31 Aug 2017.

[10] John A. Stankovic,”Research Directions for the Internet of Things”, IEEE, IEEE, 18 March 2014.

[11] Qianao Ju and Ying Zhang, “Predictive Power Management for Internet of Battery-Less Things”, IEEE, IEEE, 06 February 2017.

[12] S. Toklu and O. Ayhan Erdem, 'BSC-MAC: Energy efficiency in wireless sensor networks with base station control', Computer Networks, vol. 59, pp. 91-100, 2014.

[13] Sanchez, E.R., Montrucchio, B., Murillo, L.M., Rebaudengo, M., “Adaptive Fuzzy-MAC for Power Reduction in Wireless Sensor Networks”, NTMS, IFIP International Conference, 2011.

[14] Shahgoshtasbi, D., Jamshidi, M.M., “A new Intelligent Neuro-Fuzzy Paradigm for Energy-Efficient Homes”, Systems Journal, IEEE, June 2014.

[15] Mario Collata, Antonio Messineo, Giuseppina Nicolosi, Giovanni pau, “A self-powered Bluetooth network for intelligent traffic light junction management”, WSEAS Sci Appl, 2014.

[16] Garg, S.; Kalia, M.; Shorey, R., “MAC scheduling policies for power optimization in Bluetooth: a master driven TDD wireless system”, Vehicular Technology Conference Proceedings, Tokyo, 2000.

[17] Kawaljeet Kaur and Kiranbir Kaur, “A study of Power Management Techniques for Internet of Things (IoT)”, ICEEOT , IEEE, 24 Nov 2016.

[18] https://www.design-reuse.com/articles/42705/power-management-for-iot-soc-development.html

[19] Samantak Gangopadhyay, Saad Bin Nasir and Arijit Raychowdhary, “Intergrated power management in IoT devices under wide dynamic ranges of operation”, DAC, IEEE, San Francisco, CA, USA, 27 July 2015.

[20] Qianao Ju and Ying Zhang, ”Predictive Power Management for Internet of Battery-Less Things”, IEEE, IEEE, 06 February 2017.

[21] Anil Kanduri, Mohammad-Hashem Haghbayan, Amir M. Rahmani, Pasi Liljeberg, Axel Jantsch, Hannu Tenhunen, and Nikil Dutt, “Accuracy-Aware Power Management for Many-Core Systems Running Error-Resilient Applications”, IEEE Trans, IEEE, 28 April 2017.

[22] Sarkar, S., S. Dabral, P.K. Tiwari, and R.S. Mitra, "Lessons and Experiences with High-Level Synthesis", IEEE Design and Test of Computers, IEEE, 2009.

[23] iot.ieee.org

[24] e2e.ti.com

[25] www.electronicproducts.com

[26] www.design-reuse.com

[27] Saroj Mondal, Roy Paily, “Efficient Solar Power Management System for self-powered IoT Node”, IEEE Transactions on Circuits and Systems, IEEE, 13 June 2017

[28] http://digsys.upc.es/ed/ISESC/IoT_Keysight_5992-1192EN.pdf

[29] https://e2e.ti.com/blogs_/b/connecting_wirelessly

[30] https://iot.ieee.org/newsletter.html