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Green IoT Systems: An Energy Efficient outlook

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Abstract-*The Internet of Things (IoT) is an approaching and trending concept that has gained fame in the recent times. The large number of high performance and complicated devices connected to the IoT system devours huge amount of energy. Thus, the energy consumption problem in IoT systems is an significant research focus. Green IoT represents the issue of minimizing the energy consumption of IoT devices which leads to a sustainable environment for IoT systems. This paper grants the various techniques on energy optimization in IoT. We investigated the literature, categorized the existing energy efficient techniques and presented the open challenges and research opportunities that can help the research community. The major contribution of this paper is that it systematically summarizes and analyzes the existing energy aware techniques in tabular form on the basis of different layers and components of IoT.*

Keywords: Energy efficiency, Internet of Things, green IoT, power hungry IoT components.

1. INTRODUCTION

Due to rapid advancement in the digital technology, there is a big transformation in almost all the sectors of work. There has been an increasing trend towards the usage of smart and connected devices which has made the Internet of Things (IoT) very popular among the public. IoT is the global network infrastructure consisting of a variety of devices, e.g. sensors, actuators and appliances that are embedded in the physical objects. They have the capacity to sense, process and communicate information over the network. The large number of sensing devices, communication technologies and processing elements are involved in the development of any IoT based system. A large number of devices are connected and huge volume of data is transferred over the network and processed using variety of processors. Although, sensing devices and processing elements are mostly battery operated, they need to be capable of providing high performance. Moreover, the communication and network devices should provide uninterrupted connection for the QoS of the system. These QoS criteria cause these components to consume more energy. Thus there is a need to focus on energy efficiency aspects of the components that compose an IoT system. This paper discusses the initiatives and efforts taken by the current researchers to construct energy efficient IoT systems.

The existing survey on improving energy consumption in IoT systems mainly focused on the energy consumption in communication, architecture and processing [1]. This paper elaborates many existing approaches that make IoT energy efficient by considering the components at different layers of IoT system. The objective of this research is to present the current research in the energy efficient IoT by examining the literature, identifying the current state, describing the prevailing challenges for making the IoT systems energy efficient. This paper is organized as follows. Section II investigates the background of IoT architecture, its layers and components including identification of power hungry components in each layer.Section III describes the existing energy efficient techniques developed by the researchers. System IV presents the prevailing challenges related to energy consumption in IoT based systems and finally section V summarizes the discussion made in other sections.

2. LAYERED ARCHITECTURE OF IOT

This section presents the layered architecture of IoT indicating the power hungry components in each layer. This layered architecture aims to achieve ubiquity and pervasiveness in IoT systems by sensing, analyzing, communicating and processing of large data [2]. It is a mixture of hardware and software technologies, communication protocols and different processing technologies. The existing architectures vary with application domain and design, QoS factors, interoperability etc. It also emphasizes on the major power hungry nodes, protocols, middleware elements, and applications. The architecture is divided into five layers: Perception, Transport, Processing, Network and Application.The components associated with each layer are shown in Fig. 1. These components are segregated into power hungry and non-power hungry components.

2.1. Perception Layer

This layer senses data and provides scheduling and communication with other sensors. The important tasks of this layer are self-organized sensing and load balancing. The components of this layer include sensors, RFID, sink nodes, actuators, gateway nodes and software solutions (Application like bootstrap software) of which sink nodes, gateway nodes, actuators and passive RFID are power hungry [6,7]. The examples of sensors are medical, military, chemical, ADC Accelerometer, camera, GPS, etc [18].

2.2. Transport Layer

This layer serves as a pipe for transferring data from perception to processing layer. The components of this layer include 3G, LAN, Bluetooth, RFID, NFC, WiFietc of which NFC, WiFi, coordinators, trust center gateway, master-slave Bluetooth model are power hungry components [2]. The examples of transport layer components are tags, reader, electrometer, short range communication protocols, trust center, gateway etc [18].

2.3. Processing/Middleware Layer

In this layer, large amount of data is analyzed, processed and stored. This layer provides services to the lower layers, allocates resources for efficient storage in virtual and physical machines and converts the data into required form. The components of this layer include processing elements, middle wares and databases of which the processing elements such as virtual machines, resource allocator, data centers, analytic center and information convertor are power hungry components [17]. The examples of processing elements are online servers, data centers, micro controllers, microprocessors etc, while the examples of middleware are semantic based and service based middleware, event based and process oriented middleware, Contiki, TinyOS, RTOS and databases such as data warehouses, allocator CPU.

2.4. Network Layer

This layer provides communication between devices of other layers as a whole system model. The components of this layer include WSN nodes, cloud servers and big data gateway nodes of which WSN nodes, base stations, big data centers and routing gateway nodes are power hungry components. The examples of WSN elements are low power devices, sensing, computing, power and routing components, hubs and switches, IoT cellular operators, remote transmitting nodes and examples of cloud servers are WebBroker and Virtual devices [3].

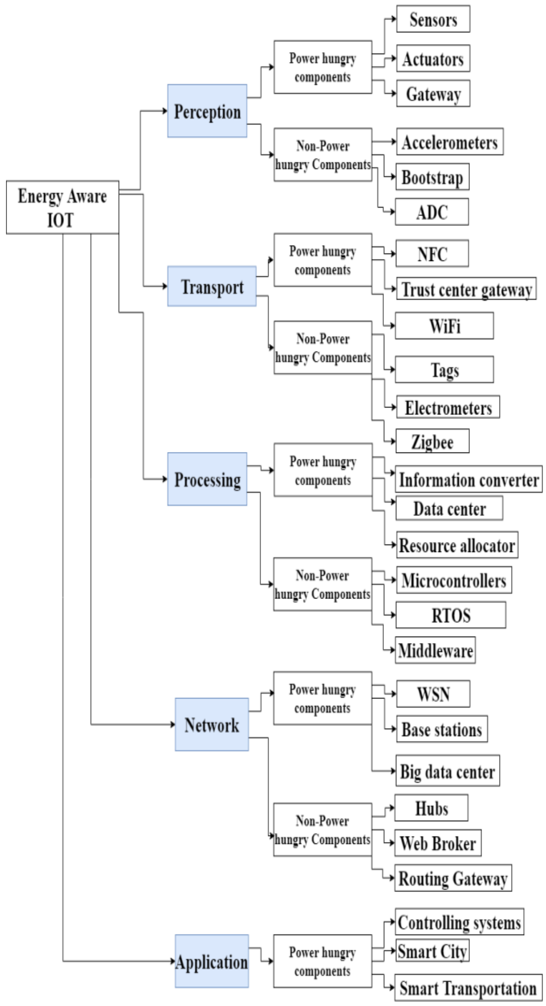

Fig 1: Classification of IoT components

2.5. Application Layer

This is an abstract layer for the users to avail services of the lower layers [5]. It provides the visualization of processed data in the form of intelligent tasks. The example of

applications include smart homes, smart buildings, smart vehicles, health care, smart environment, supply chain management, energy conservation, etc of which control systems usually are power hungry appliances.

3. ENERGY OPTIMIZATION TECHNIQUES IN IOT

Primarily, energy is consumed in various tasks such as sensing, communicating, processing and actuating within and across the layers. The overall architectural elements communicate with each other and thus consume more energy. The various principles on which the energy efficient technologies are proposed in the literature include sleep off scheduling mechanism and selective sensing, data buffer delivery, minimization of data path length, wireless communication, processing of tradeoff communication, advanced communication techniques and distribution of task efficient nodes and resources on multi-core[6, 7]. These energy optimization techniques are applied under different layers of the IoT system. In this section we categorize these techniques among the layers and summarized them as follows:

3.1. Techniques under Perception and Processing layers

The power hungry components under these layers are sensor and gateway nodes that perform data sensing, monitoring, filtering, prediction and compression with processing [7].Sensors are also dependent on battery [1]. Gateway nodes (relay nodes) serve as storage buffer, control sensor resources and allow data communication. These gateway nodes calculate the sleep interval of sensor nodes on the basis of parameters like battery level of sensors, conflicting factor, quality of information(QoI), triggering of event and pass wake-up signals to control communication. Various processing and resource allocator nodes under processing layer control the gateway nodes, allocate resources and preprocess data. Thus, the components under these layers have high energy consumption. The authors in [7] suggested an energy efficient task scheduling algorithm on the basis of sleep interval of sensor nodes. This optimizes the energy consumption of sensor nodes. Dynamic voltage and frequency scaling (DVFS) technique can also be used with task scheduling algorithm to reduce energy consumption of BIG.LITTLE processor architecture [4]. Similarly, authors in [4] proposed a task scheduling on heterogeneous cores using TDMA. The selective and compressive sensing technique proposed in [8] optimizes energy. Other techniques such as QoI based sensor to task duty cycle allocation [9] and selective and compressive sensing [8] also optimize energy consumption of sensor and gateway nodes. There exists few energy efficient techniques at processing layer such as allocation of server and workload distribution at data centers [1], varied power down mechanisms [10], cooperation among the nodes while processing [11, 4].

3.2. Techniques under Transport and Network Layers

These layers address wireless sensing and networking aspects such as routing, servicing of requests and data communication mechanisms. They also include functionalities like transmission of data, neighborhood communication, retransmission and avoidance of packet collision and handshaking mechanisms [12]. These communication mechanisms consume lot of energy. In addition to this, in network transmission, location information in routing, interoperability of heterogeneous things and massive data movement consume more power [13]. With the immense hike in users and application providers, there is an increase in network traffic resulting in high energy consumption. In WSN, network sensor nodes and communication unit transmit information for a large period of time resulting in high energy consumption [14,3].The energy optimization techniques proposed in [3] include Multi-hop and cooperative multi-hop routing in WSN communication to base stations. These techniques route the changing data in hop-to-hop level thus reducing the energy consumed in long path transmission. Elias Yaacoub, Abdullah Kadri, and Adnan Abu-Dayya et.al [3] proposed two techniques that optimize the path of communication by forming clusters among the network devices and processing across the layers. This path optimization results in reduction in energy consumption. Another technique proposed by the authors [15] is based on parallel communication among the sensors and pruning of network requests using Pruned Adaptive Routing protocol. This technique provides the optimized routes to the target node thereby effectively reducing the energy consumption. There are few optimization techniques that work on hubs and switches to minimize the path length in data transmission [16].The use of System on Chip for controlling network traffic and reducing energy consumption in network communication is proposed in [17]. Dynamic downloading of packets using access points [8], shallow/deep sleep mode, check-pointing system state mechanism and data fusion techniques are energy efficient techniques existing in these layers. Mixed Integer Linear Programming (MILP) [3] and Graph algorithms [9, 1] are applied in scheduling of the communication tasks to reduce energy consumption in network communication.

3.3. Techniques under Application layer

Applications that actuate the process and display the output are highly battery constrained. Any web application, mobile sensors, actuators, control systems like HVAC have high computations since they perform the tasks like content management, web and directory services etc. Data processing on

layer. There are various energy optimization techniques existing in the literature at this layer. The author [17] uses machine learning algorithms to predict the energy consumption by detecting variousactivities in the applications. The different energy optimization techniques addressed in this layer include

MQTT (Message Queue Telemetry Transport) and CoAP(Constrained Application Protocol), CoAP an alternative to HTTP, tracking mechanism and MQTT-S/MQTT SN[14]. In a IoT systems, application like smart city uses technologies such as distributed control and fog computing that creates dynamic and distributed energy control framework. Also, techniques like mass transit gains more merit in terms of large capacity, higher delivery efficiency, low energy consumption and costs [12].

4. CHALLENGES

Even though there exist a lot of research papers on IoT systems, researchers are still focusing on identifying the power hungry components/aspects in IoT systems and are working on optimizing solutions. Some of the research efforts made by existing researchers are described in this paper. There still exist technical challenges which are listed below:

1.Design of energy efficient processing elements at the processing layer is required to be addressed as most of these processing elements consume lot of energy in storing, managing, and processing of large amount of data. 2. In perception layer, sensors should be made energy efficient high power consumption in continuous sensing mechanism.

3. Continual sensing, controlling by gateway, processing by data centers and processors, network transmission, long running applications is challenging in these devices as more energy is consumed by these devices.

4. Also, huge numbers of things interact at these layers via large amount of real-time data, interoperability and intelligent processes that need to be considered to make energy efficient system.

5. CONCLUSION

This paper reviews the most significant research carried out by the research community on the emerging issue of energyefficiency in IoT systems. The major challenges of energy efficiency in IoT based systems have been pointed out. Different from the other existing surveys, we have focused on identifying and compiling the energy optimizationtechniques that are based on two parameters: layers of IoT and components at each layer. Finally, future research challenges and problems with respect to green IoT are presented.

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