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Green Initiatives in IoT

Sudhir K. Routray[1] and Sharmila K. P.[2]
Associate Professor[1,2]
Department of Telecommunications Engineering,
CMR Institute of Technology, Bangalore, India.
E-mail: sudhirkumar.r@cmrit.ac.in[1] / hod.tce@cmrit.ac.in[2]

***Abstract*—Internet of things (IoT) is going to be ubiquitous in the next few years. In the smart city initiative, millions of sensors will be deployed for the implementation of IoT related services. Even in the normal cellular architecture, IoT will be deployed as a value added service for several new applications. Such massive deployment of IoT sensors and devices would certainly cost a large sum of money. In addition to the cost of deployment, the running costs or the operational expenditure of the IoT networks will incur huge power bills and spectrum license charges. As IoT is going to be a pervasive technology, its sustainability and environmental effects too are important. Energy efficiency and overall resource optimization would make it the long term technology of the future. Therefore, green IoT is essential for the operators and the long term sustainability of IoT itself. In this article we consider the green initiatives being worked out for IoT. We also show that narrowband IoT as the greener version right now.**

Keywords— Internet of Things; green Internet of things; energy efficient Internet of things.

I. Introduction

Internet of things (IoT) is going to be an integral part of the modern cellular networks. IoT can have its own network and based on that it will have its own functions. It is also possible to use IoT as value added services in cellular infrastructure. Either way, IoT will have a large impact on the communication and sensing applications. For the smart city initiatives, IoT will need millions of sensors in a large coordinated network. This is going to be a large investment by the operators and vendors. Also, the operational expenditures (OPEX) in the long term have to be considered for overall efficiency of IoT. In fact, OPEX over the duration of several years will have larger costs than the initial capital expenditure. Thus, green initiatives or the energy efficient principles have to be adopted for the long term.

Green technologies and energy efficient processes in IoT are well researched areas in which optimization of resources takes the central position. Several works have been done on IoT to make it more energy efficient. In [1], the green initiatives for smart world have been addressed. It covers several new and progressive trends and technologies which can make the overall IoT networks energy efficient. Segment wise, greening processes have been addressed through the existing information and communication technologies (ICTs). In [2], a survey of the IoT marketplace has been presented which provides the industrial demand and applications of IoT in different processes. It shows that manufacturing and automation will have a large share of industrial IoT. In [3], a similar survey is provided which focuses on the technology prospective of IoT. It emphasizes that the wide deployments need to be energy efficient for the practical reasons. In [4], a comprehensive survey on the practical aspects of IoT has been provided. It first deals with the enabling technologies that make IoT a reality and then show the main protocols which are instrumental in the IoT operations. Then it provides a long list of applications in which IoT can play a significant role. The authors pointed that the overall success of IoT is very much dependent on the efficiency of the entire IoT networks, their components and end devices. In [5] and [6], the energy aspects of 4.5G and 5G are dealt with detailed information. Green initiatives of 5G are discusses in depth in [5]. In [7], the recent trends of consumer electronics driven data communication networks are provided. It shows the volume of the resources needed for the global communication networks. In [8], sustainability aspects of communication networks have been presented. It shows the carbon emission contributions of global communication sector. Finally, it provides outlooks for overall sustainability. In [9], research and development initiatives of 5G and IoT are presented in which energy efficiency and overall network optimizations are analyzed. In [10], the green radio communication technologies and emerging methods are highlighted with proper background information. It also provides insights for emerging networking technologies for energy efficiency. In [11], 5G energy efficiency related aspects are presented. In [12] and [13], energy efficiency related aspects of the Internet and wireless Internet in specific have been discussed. It also covers the energy aspects related to IoT. In [14], green technologies for clouds are analyzed. Cloud energy efficiency is essential for green IoTs as clouds are going to be their integral parts in the long term.

In this article, we provide the green initiatives being taken to make the IoTs efficient in resource utilization. We present the overall features of IoT, its deployment issues and the commonly expected features. We show that narrowband IoT (NBIoT) is certainly greener than other IoTs right now. We present its main features, deployment options and applications.

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We also present the main stream trends being adopted for energy efficiency in IoTs.

The reminder of this paper is organized in four sections. In Section II, we present the broad views of current IoT trends and technologies. In Section III, we present the leaner, thinner and greener version of the current IoTs, commonly known as narrowband IoT. We also presented its deployment options and applications in different sectors. In Section IV, we present the overall initiatives being taken in the recent times to make IoT energy and resource efficient. In Section V, we conclude with the main points of this article.

II. Broadview of Current IoT Paradigm

Sensor networks are in use since last several decades. These sensor networks serve several measurement and sensing operations. Wireless sensor networks (WSNs) are used in several applications which are very much distributed and normally have a centralized control. The popularity of the WSNs went up with the popularity of the sensors to keep track of the essential parameters in different processes and environments. The densification of the sensors in WSN was a trouble for the central control. Therefore, there were several proposals to connect the sensors in a well-defined networked framework. Most of the popular and feasible proposals suggested for the interconnection between the sensor networks and the existing communication networks preferably through the Internet and the cellular communication networks. That is how the idea of IoT came into light. In fact, IoT is much more diverse than WSNs. IoT covers both the mobile and static objects in its sensing and associated information processing.

According to International Telecommunication Union (ITU), IoT is a global infrastructure for information society, that enables the advanced services by interconnecting things based on the existing and evoling ICTs. It clearly indicates that the IoT will work as a part of the ICT using its standards and technologies. In [4], IoT elements have been separated and classified. According to [4], there are six elements of IoT: identification, sensing, communication technologies, computing, services and semantics. Each element is important for the overall functions of IoT. In a large IoT network all these six elements are found. However, in the small and ad hoc IoT networks only the essential elements are found. For energy efficeincy, proper coordination is required between these elements.

III. Narrowband IoT: the Green IoT

NBIoT as the name suggests, uses narrow bands for its operations. It needs 180 kHz to 200 kHz for its processes. In LTE Release 13, 180 kHz has been proposed as the operating bandwidth for NBIoT. It is a low power wide area (LPWA) technology, good for large scale deployment. It is leaner, thinner and greener than other IoTs proposed in the recent years. NBIoT can be deployed in both the cellular and non-cellular forms. Cellular forms are popular as they can use the existing cellular architecture for its operations. In LTE Release 13, it has been standardized according to the compatible LTE provisions and proposed for connected living [15].

A. *Basic Green Features of NBIoT*

Main attraction of NBIoT is its LPWA nature. It can save a large amount of energy in the network. Its architecture and protocols have been standardized for different environments. NBIoT bandwidths have been agreed by the standardization committee in Release 13. Depending on the situation, different spectral bands will be used by the operators. According to Release 13 of 3GPP LTE, the maximum usable bandwidth of an end device is 200 kHz. In fact, for the communication purpose 180 kHz is used [16] – [21]. At this bandwidth, the upper limits of the uplink and downlink data rates are set at 150 kbps. Half duplex mode is proposed for NBIoT communications [17]. The power from the transmitter is kept quite small so that a single battery can supply power to the NBIoT devices or nodes for more than 10 years. In fact, two power levels have been specified: 20 dBm and 23 dBm [21].

B. *NBIoT Architecture*

A systematic NBIoT architecture is required for its planning, dimensioning, cost estimation, design and final deployment. It does not have a legacy to follow as it is one of the earliest IoTs of its type. However, it is similar to the WSN and the WSNs are there for several years. The existing WSN architecture and topologies can be helpful in its further advancement. It is noteworthy that WSNs did not have a structured and well defined architecture like the cellular systems such as the LTE networks which will form the backbone of NBIoT. Therefore, an LTE cellular framework for NBIoT is the right choice at the moment [17]. The layered structure of NBIoT is helpful in its planning and deployment. In Release 13, several specifications for different layers have been mentioned. NBIoT can be separated into 6 layers as shown in Fig. 1. The physical layer is at the bottom and it is normally the air interface. Physical layer does the similar functions as other WSNs and some added functions as defined in Release 13. Above it is the medium access control (MAC) layer. This has the similar functions like the MAC layer of other networks. It incorporates the protocols for medium access and multiple access techniques. There is a radio link control layer in between the MAC and the upper layers. This layer makes the adaptation of the MAC layer information for radio links. Above it is the packet data convergence protocol layer which provides routing, traffic scheduling, networking and other related tasks. Then above it is the radio resource control layer which takes care of the radio resources of the packets in the channels. NBIoT uses user datagram protocol (UDP) and other cellular mechanism to carry this function [18]. UDP is effective in the wireless networks and thus suitable for NBIoT as well. The topmost layer is the Non-Access Stratum (NAS) which establishes the communication between the user equipment (UE) and the main server of the NBIoT also known as NBIoT central node.

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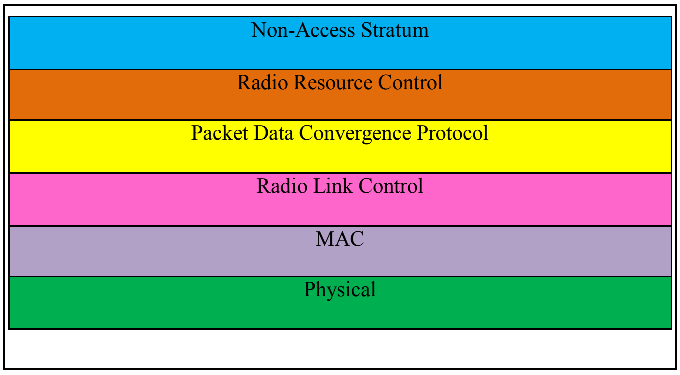

Fig. 1: The six layers of NBIoT architecture. In the respective layers, the associated protocols too have been shown which are essential for the overall function on NBIoT.

C. Deployment Options for NBIoT

NBIoT deployment options have been agreed in Release 13. According to it, NBIoT can be deployed in three different forms. The first being the standalone deployment in which an independent microwave band is provided in the 700MHz or 800 MHz range for its deployment. The second one is the guard band deployment in which the spectrum for IoT is the unused GSM and LTE guard bands. These guard bands are normally not used for communication purposes in GSM and LTE cellular systems. With the arrival of NBIoT, these guard bands find a new application. The third one is the in-band deployment. In this case, some part of the GSM or LTE spectrum is allocated to the NBIoT. In Fig. 2, we show these 3 deployment scenarios.

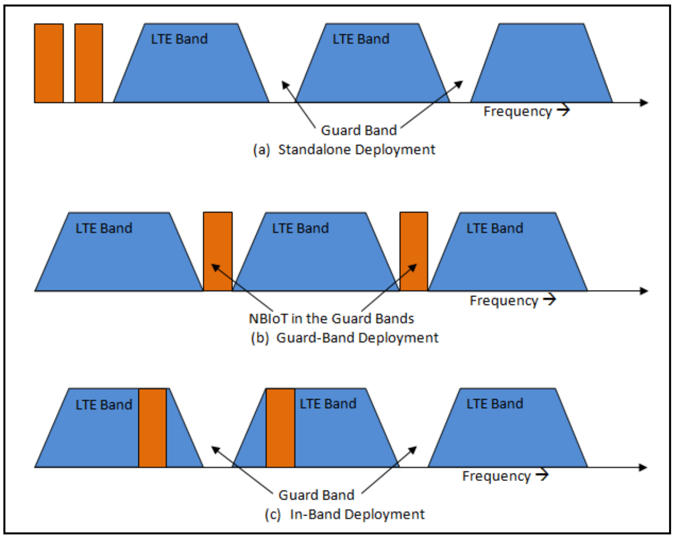

Fig. 2: Deployment options for NBIoT in different bands (blue bands are for LTE/GSM, and orange bands are for NBIoT). In (a), it is in the standalone mode; in (b), it is in the guard band; and in (c), it is in the LTE/GSM bands.

D. Applications of NBIoT

Several applications of NBIoT are possible and it can be deployed for any LPWA applications in which the six elements of IoT are available. Both local and nonlocal applications of NBIoT are equally possible. Emerging applications are found in several technology and social sectors with every passing month. There are several new sectors in which NBIoT has potential applications. Some of these applications are indoor and the others are outdoor. NBIoT can be instrumental in designing smart homes and smart cities [16]. Similarly, it can help in healthcare as well as the security monitoring of public places. In Fig. 3, we present some typical sectors in which NBIoT can have significant role. These sectors are: smart city; smart home; manufacturing; pet tracking; kids' tracking; healthcare monitoring; safety and security applications; agriculture and farming; energy and utility management; automobile and vehicular management; retail management; policing and law enforcement assistance; detection of environmental degradation; waste management; and several other LPWA applications.

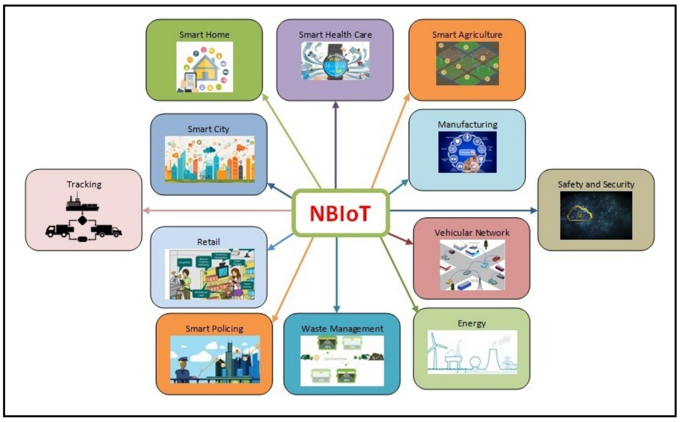

Fig. 3: Different applications of NBIoT. New applications emerge every month in different sectors.

IV. OTHER INITIATIVES FOR GREEN IOT

Overall energy efficiency of a network depends on the energy efficiency of its components. IoT has several parts and the energy efficiency of each part and each component is significant in the overall greenness of the whole network. The main parts of a typical IoT are: radio frequency identification (RFID) unit; sensing unit; cloud infrastructure; machine to machine (M2M) communication unit; data center; and ICT unit. All these units need to be green for overall green initiatives in IoT.

Energy efficient algorithms and protocols are in use to improve the energy efficiency of RFID unit. Even the size of the RFID hardware is optimized for energy efficiency. Majority of the sensing units in IoT are WSNs. These WSNs use several types of architecture and protocols for their operations. These architectures and protocols are optimized for IoT environments. Cloud infrastructure is essential in today's communication networks. It has important roles for IoT. The green initiatives in clouds are very much important for overall energy efficiency. M2M scenarios are very common in IoT. It is being made energy efficient in several new methods. Communication is being made energy efficient in several ways. Spectral efficiency and full duplex methods are energy efficient because they use less energy per bit. Data

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centers store and retrieve information time and again. Their efficiency is increasing every year through efficient algorithms and protocols. Overall ICT components are optimized in some form or the other. Using all these initiatives, IoT can be made really green.

V. CONCLUSIONS

Green initiatives in IoTs are essential as the smart cities are being developed all across the globe. In each city several million sensors are being deployed for the smart applications. These huge numbers of sensors need their own energy for their operations. Energy harvesting is an option. However, overall system efficiency is more important. NBIoT is certainly a popular LPWA technology and greener than other versions of the IoTs. It is preferred in the current cellular architecture. It is greener than other versions of the IoTs at the moment. However, each segment of each IoT network should be made efficient. Then only overall greening operations will be successful.

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